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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

SCOPUS

ZDB Zeitschriftendatenbank

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- 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.

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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.
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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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A Shared Journey in Colour

Deputy Editor's note

Dear Readers,

This new issue of Color Culture and Science Journal once again reminds us why colour is such a wonderfully stubborn subject: it refuses to stay in one place. The contributions collected here move across perception, design, heritage, digital practices, and sustainability, showing, yet again, that colour is never “just” an aesthetic choice. It is a way of thinking, measuring, designing, preserving, and sometimes even arguing (politely, of course). Seeing these different perspectives meet in the same issue is one of the quiet pleasures of working on this journal.

This issue also comes with a small personal announcement. After several years as Deputy Editor of CCSJ, it is time for me to step aside from this role. It feels a bit strange to write this, partly because time has flown, and partly because being an editor is one of those jobs you only fully appreciate once you realise how many emails, spreadsheets, and last-minute miracles it involves. Looking back, it has been a genuinely rewarding experience: helping to grow the journal, welcoming new reviewers and editors into the team, and contributing to milestones that once felt rather ambitious, such as seeing CCSJ indexed in Scopus. That achievement, in particular, is a collective one, and I am proud to have been part of the journey that led us there.

I am not going very far, though. I will continue to serve the journal as an Associate Editor, which means I still get to read interesting papers, work with great colleagues, and occasionally worry about deadlines, just in slightly different proportions.

I would like to thank, from the bottom of my heart, the people who first introduced me to CCSJ, those who mentored me along the way, and all the colleagues who have worked patiently, generously, and always on a voluntary basis to keep this journal alive and growing. CCSJ is very much a community project, built on shared commitment, curiosity, and a remarkable amount of goodwill. Working together in this spirit has been one of the most enjoyable parts of this experience, and, yes, also one of the most human ones.

Finally, thank you to the authors, reviewers, editors, and readers who continue to trust and support the journal. I am confident that Color Culture and Science Journal will continue to evolve as an open, interdisciplinary, and lively forum for colour research, and I am very happy to remain part of that story.

Best Wishes,

February 2026
The Deputy Editor Alice Plutino, PhD

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An unsupervised method to increase film color restoration sustainability for small cinematheques

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ABSTRACT

Digital film restoration plays a crucial role in preserving audiovisual heritage, offering a unique potential to enhance image quality and accessibility. However, it faces significant challenges in terms of technological and, even more critically, economic sustainability. This study proposes an automated, unsupervised method to optimize film restoration workflows, reducing costs and resource consumption, particularly for small cinematheques with limited budgets.

To illustrate this point, we present a comparison between two case studies. The first is the film “The Funerals of the Bombing of Piazza della Loggia in Brescia”, shot by Mario Bertoli in 1974 and currently preserved in the archive of the “Casa della Memoria” in Brescia. This historically significant document allows for a comparison of traditional and digital restoration techniques in terms of cost and quality. The second case study focuses on “La Lunga Calza Verde”, a 1960 animated short film directed by Roberto Gavioli and based on a script by Cesare Zavattini. Created for the centenary of Italy’s unification, it was entirely restored using the proposed automated digital process.

These examples demonstrate the feasibility and advantages of an unsupervised approach and highlight how it can enhance the sustainability of film restoration for small cinematheques.

KEYWORDS Film restoration, Color restoration, Sustainability, Film Digitization, Digital Restoration, Spatial color algorithms, Unsupervised restoration

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1. Introduction

Digital film restoration plays a fundamental role in preserving the audiovisual heritage and make them accessible to a wider public. However, current practices present important critical issues, especially in terms of technological and economic sustainability; these difficulties can be critical in the case of foundations, libraries and small film libraries with limited resources to deal with the costs and complexities of the restoration process.

Digital technologies applied to film restoration have generated a limited number of commercial software with which very complex operations can be performed. However, apart from the payment of a licence fee, the biggest cost is the work of personnel highly trained in their specific use: the effectiveness of operations such as dust and scratch removal and color correction are closely linked to the software chosen and the level of training of the operators. Moreover, these software intended for a professional niche, when not discontinued, pay for a certain slowness in their development due to their small user base, unlike widespread applications dedicated to graphics such as, for example, Adobe Photoshop®.

This study proposes the evaluation of the use of Spatial Color Algorithms (SCAs), based on automated and unsupervised methods, compared to a supervised digital restoration process. The aim is to consider them to optimize workflows in film restoration, reducing operational costs, while improving efficiency and technological accessibility.

In order to highlight the differences between the classic supervised digital restoration and the automated approach enabled by SCAs, we will analyze two case studies: the restorations of the 1974 documentary "The Funeral of the Piazza della Loggia bombing in Brescia" (Plutino et al. 2018) and the 1960 animated short film "La Lunga Calza Verde" (Berolo et al., 2012).

The examples given in this article show how the adoption of innovative technologies can improve the sustainability of restoration by making it, with a small loss in quality, more cost-effective.

2. The concept of sustainability in film conservation and restoration

The original concept of sustainability (Brundtland, 1987) has over time been stretched to include the economic, social, technological and cultural dimensions of all human activities.

In the audiovisual sector sustainability is relevant at all stages (Meilani, 2021) but in the context of film preservation and restoration it acquires a specific meaning. Here, sustainability concerns the optimization of resources (both material and energy), cost containment, and the preservation of historical and artistic value, while ensuring broad accessibility of restored works (Lopera-Mármol and Jiménez-Morales, 2021).

Preservation challenges differ between analogue and digital formats. Film materials are inevitably subject to chemical and physical degradation, which can only be slowed through strong controlled storage conditions (Harrison, 1997; Reilly, 1998; Plutino and Bellotti, 2022; RTI I. P., 2021). Digital archives, while avoiding physical decay, face other sustainability issues: planned obsolescence of storage media like RAID or LTO, continuous migration requirements, and the high energy demand of data centers (Antoniazzi, 2020). These factors make long-term digital preservation costly both financially and environmentally.

Film restoration is inherently expensive because all steps in the standard workflow require the use of high-quality hardware and software equipment and highly qualified personnel. In this sector, sustainability emerges not only as an environmental requirement, but also as an economic and cultural strategy, safeguarding the long-term accessibility of the audiovisual heritage.

3. The context of restoration

In sustainable film restoration, cost represents a decisive constraint, particularly for small cinematheques. As noted by The Film Foundation, expenses vary significantly according to a film's condition, length, and technical requirements: black-and-white features with sound may cost between USD 50,000 and 250,000, while color features with sound typically range from USD 80,000 to 450,000 for photochemical processes, with even higher figures for 2K or 4K digital workflows (The Film Foundation, n.d.). Such figures illustrate the financial pressures faced by smaller institutions and underline the need for more sustainable, cost-efficient strategies.

Small archives are further challenged by limited resources, which often compel them to prioritize works with greater public or commercial appeal, leaving lesser-known yet culturally significant materials at risk of neglect. Dependence on expensive proprietary software and training, coupled with the absence of accessible open-source alternatives, undermines institutional autonomy and compromises long-term sustainability. While international initiatives promote collaboration and resource sharing, smaller cinematheques remain underrepresented due to scarce specialized personnel and the limited visibility of their collections.

To address these challenges, automated and unsupervised restoration algorithms - such as Spatial Color Algorithms (SCAs), designed to minimize manual intervention while preserving restoration quality (Rizzi et al., 2014) offer a promising solution. By reducing operator involvement, limiting training requirements, and mitigating reliance on proprietary tools, they help lower costs and processing times, enabling institutions to tackle a larger share of their holdings within existing constraints. Importantly, their open-source availability allows adoption without the financial and contractual limitations of commercial solutions.

Central to this approach are SCAs (Rizzi and McCann, 2007), which perform spatial analysis to detect and correct deviations in color and contrast while preserving image integrity. Their effectiveness depends on the state of the original material: since they do not perform scratch removal, in some cases they provide a complete restoration solution, while in others they serve as a preliminary stage within a traditional workflow, in both instances reducing the overall cost of the process.

The following section outlines the methodological framework of this approach, presenting the underlying algorithms, workflow configuration, and comparative performance against operator-driven methods. This provides the basis for a critical evaluation of its potential to reconcile cost-effectiveness, operational efficiency, and preservation quality.

4. Two case studies

4.1. The restoration of “The Funerals of the Bombing of Piazza della Loggia in Brescia” film (1974)

The first case study concerns the restoration of “The Funerals of the Bombing of Piazza della Loggia in Brescia”, as described by Plutino et al. 2018. The film constitutes a primary historical source, bearing witness to a pivotal moment in the political and civic history of Brescia (Italy).

The material presented heterogeneous preservation conditions: the footage of the explosion day was severely degraded, whereas the funeral scenes were comparatively well preserved, though the film overall exhibited common issues such as scratches, dust, and color fading.

The restoration was carried out at the I’ve Seen Things Research Lab following a structured workflow: historical and technical analysis; digital scanning; primary color correction; dust and scratch removal with frame stabilization; repair of damaged frames; secondary color correction and scene harmonization; and final editing (Plutino et al., 2018). Digitization alone required about 15 hours of automated acquisition, with operator supervision to ensure the film’s physical integrity. Primary color correction involved calibration of white balance, saturation, and contrast across 120 scenes, a task that demanded 62 hours of work and the expertise of senior editors for the most compromised sections.

The subsequent digital restoration phase - dust and scratch removal, stabilization, and replacement of irrecoverable frames - proved particularly labor-intensive, requiring approximately 88 hours. Operator expertise was decisive here, as incorrect parameter settings could compromise detail and overall image quality. Secondary color correction, essential for harmonizing individually processed scenes, required the direct involvement of the project supervisors. The final stage included editing and export in two formats: MPEG-4 AVC (H.264), optimized for distribution, and DPX, a lossless format suitable for long-term preservation but memory-intensive.



Fig. 1. On the left the original frames of the short film “The Funerals of the Bombing of Piazza della Loggia in Brescia” compared to the restored version on the right (LAB MIPS, 2020).

In total, the project lasted around two and a half months, amounting to roughly 200 hours of work and involving eight people - five students and three experienced editors. The case illustrates how film restoration combines automation with significant manual and expert intervention. While highly trained operators are indispensable for color correction and quality control, less specialized personnel play a crucial role in supervising automated processes and performing manual tasks such as dust and scratch removal, which remain essential to achieving reliable results (Plutino et al. 2018).

4.2. The restoration of “La Lunga Calza Verde” (1960)

The second case study concerns the restoration of the animated short film “La Lunga Calza Verde”, directed by Roberto Gavioli and produced by Gamma Film in 1960 (Berolo et al., 2012).

The intervention, carried out in 2012 by the MIPS Laboratory of the Giovanni degli Antoni Department of Computer Science at the University of Milan, represents a comprehensive example of an unsupervised restoration performed using SCAs.

SCAs, widely employed in photographic image enhancement, operate according to perceptual principles

inspired by the human visual system, focusing on the appearance of color rather than its physical measurement (Berolo et al., 2014).

While this approach is effective in correcting degradations such as fading or contrast loss, it requires careful supervision in the audiovisual field, since directors may have intentionally introduced

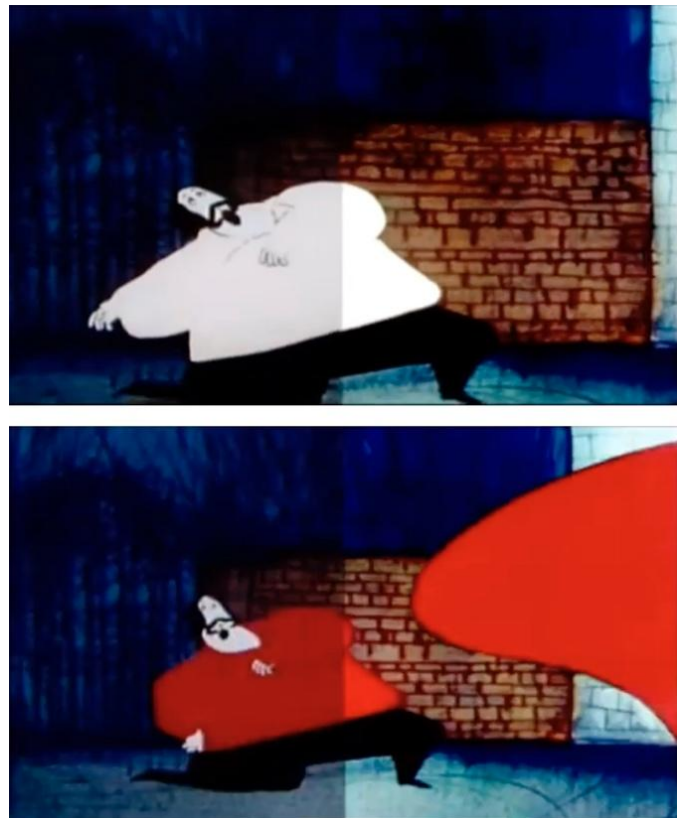
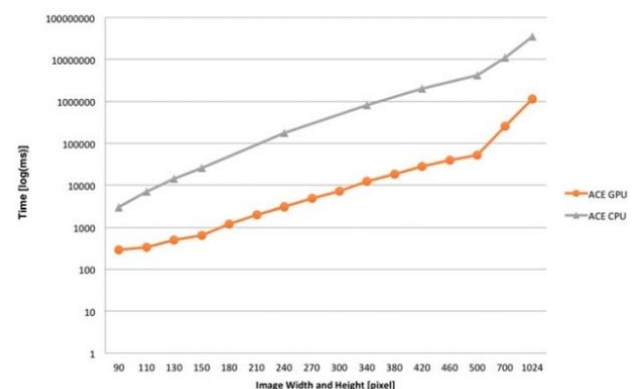


Fig. 2. Original frames (left) from “La Lunga Calza Verde” set against the restored version (right) (LAB MIPS, 2018).

Effects - such as color dominance or limited dynamic range - that must be preserved as part of the work’s aesthetic identity. SCAs are, in general, computationally expensive, with algorithmic complexity ranging from $O(N \log N)$ to $O(N^2)$, where N is the number of pixels in the image. To address this limitation, two main strategies can be adopted: smarter software implementation and/or efficient parallel processing. One example of software optimization is the Local Linear Look Up Table (LLUT) (Gatta et al., 2006; Artusi et al., 2006), which significantly reduces computational time while introducing only a minor loss in filtering quality. Moreover, the computational structure of SCAs makes them particularly suitable for parallelization on many-core or multi-core architectures, such as modern GPUs. Implementations on GPUs are relatively straightforward when using high-level programming APIs like CUDA or OpenCL, although challenges remain in optimizing data transfer and memory access within the GPU hierarchy. As shown in Tab. 1, a comparison (in logarithmic scale) between CPU and GPU implementations of the ACE algorithm underscores these performance differences. The CPU version, written in C++

and executed in single-core mode on an Intel Xeon Quad Core E5-2609 2.40GHz running Windows 7, was compared with a GPU version implemented in OpenCL on an NVIDIA Quadro 4000 within the same workstation. Results showed that GPU computation delivered speed-up factors ranging from 10x to 80x, with an average improvement of 45x.

The combination of software-level optimization and parallel computing thus makes it possible to overcome the computational limitations of SCAs, opening the way to their use for high-resolution content and high frame-rate processing. The restoration of “La Lunga Calza Verde” was



Tab. 1. Comparison between computational performances of CPU and GPU implementations of ACE algorithm. The computational times (Y axe) are shown using a logarithmic scale, on the X axe are showed the images width in pixel. (Rizzi et al., 2014).

conducted on an Intel Xeon Quad Core E5-2609 2.40GHz, a processor introduced in 2012. For a meaningful comparison, its performance can be contrasted with that of a more recent Intel Core i9-13900K (2022).. On the Cinebench R15 benchmark, the i9-13900K achieves a single-core score of 330 compared with 73 for the Xeon, and a multi-core score of 6,141 versus 606, while requiring only about 40% more power consumption (CPU-Monkey, 2024). These figures suggest a performance increase of nearly an order of magnitude, illustrating the dramatic advances in processing power available to contemporary restoration workflows.

5. Comparative analysis of the two restoration approaches

5.1. Introduction to the Case Studies

The two case studies presented - the restoration of “The Funerals of the Bombing of Piazza della Loggia in Brescia” (1974) and “La Lunga Calza Verde” (1960) - highlight two fundamentally different approaches to film restoration: a manual, supervised, multi-step process one and a largely automated, unsupervised, algorithm-driven process. Both aim at preserving and enhancing the visual quality of historical audiovisual materials, yet they differ substantially

in workflow, resource requirements, technological reliance, and the role of human expertise.

5.2. Workflow and Methodology

The restoration of “The Funerals of the Bombing of Piazza della Loggia in Brescia” followed a classical sequence of steps: digitization, multiple stages of color correction, manual and semi-automated defect removal, and final editing. Every stage required careful human intervention, particularly for maintaining color fidelity and correcting scratches and dust.

Conversely, “La Lunga Calza Verde” employed SCAs, which, after initial parameter tuning and key frame selection, enabled fully automated enhancement across entire scenes. Human involvement was limited to verification and final adjustments, significantly reducing manual labor while maintaining control over key restoration decisions.

5.3. Human Resources and Expertise

The supervised restoration of “The Funerals of the Bombing of Piazza della in Brescia” required eight people, including three highly experienced professionals, over

approximately 200 hours. Skilled personnel were critical for accurate restoration, especially in color grading and handling severely degraded portions.

In contrast, the “La Lunga Calza Verde” restoration, while still needing expert input at key decisions, reduced manual labor significantly by leveraging SCAs, minimizing total time through parallel processing and algorithmic optimization.

The difference in resource allocation and efficiency is summarized in Tab. 2, comparing film durations, total work hours, and personnel. Although the films have almost identical durations, “The Funerals of the Bombing of Piazza della in Brescia” required more than twice the working hours of “La Lunga Calza Verde”. While the workload was distributed across eight people (≈ 25 hours each) for the former, the latter concentrated 90 hours on a single operator. Normalized by person-hour, “La Lunga Calza Verde” is ≈ 2.3 times more efficient, highlighting the impact of workflow design, algorithmic support, and personnel organization on restoration sustainability.

	A) The Funerals of the Bombing of Piazza della Loggia in Brescia	B) La Lunga Calza Verde
Film lenght	19' 50"	20' 22"
People involved	8	1
Total hours worked	200 hrs	90 hrs
Hours worked per minute of film	10,10 hrs/min	4,4 hrs/min
Minutes of film for every hour of work	0,10 min/hr	0,233 min/hr
Hours per person (if distributed evenly)	25 hrs/prs	90 hrs/prs
Relative speed (per capita productivity)	—	$\approx 2,33x$ faster than A

Tab. 2. Comparative data on the restorations of “The Funerals of the Bombing of Piazza della Loggia in Brescia” (1974) and “La Lunga Calza Verde” (1960). The table summarizes film duration, total working hours, personnel involved, and derived indicators of productivity and efficiency (Elaboration made by the Authors).

5.4 Technological Requirements and Performance

Technologically, the “The Funerals of the Bombing of Piazza della Loggia in Brescia” restoration depended on specialized hardware (film scanner) and professional video editing and color correction software, but its efficiency was bounded by the speed of manual intervention.

“La Lunga Calza Verde” restoration, conversely, showcased the potential of computational acceleration: GPU-based SCAs implementations achieved performance gains of up to 80x compared to CPU-only execution, making high-resolution automated restoration feasible even on mid-range hardware of the time.

5.5 Aesthetic and Curatorial Considerations

The supervised workflow applied on “The Funerals of the Bombing of Piazza della Loggia in Brescia” allowed curators to make context-sensitive decisions throughout the process, an advantage when dealing with historically significant footage where visual authenticity must be preserved with the highest fidelity. The automated SCAs-based workflow, instead, while highly efficient, carries inherent risks of overcorrection or unintended alteration of artistic intent—risks that can be mitigated but not eliminated through careful parameter tuning and targeted human review.

5.6 Sustainability and Scalability

The automated approach demonstrates a model with reduced human labor and scalable computational solutions, making it feasible for smaller archives to process larger volumes of material at lower cost once the necessary infrastructure is available.

Nevertheless, for complex restorations of documents, with atypical visual characteristics, the labor-intensive supervised approach remains the most reliable option to ensure authenticity.

5.7 Towards Hybrid Workflows

The comparison suggests that hybrid workflows - integrating the speed of automated SCAs with targeted expert oversight - could provide the optimal balance between efficiency, quality, and resource allocation, particularly for small and medium-sized archives facing both budgetary and preservation challenges.

6. Conclusions

The comparative analysis of the two case studies shows that unsupervised digital restoration methods based on SCAs can improve the sustainability of film conservation, especially for small film libraries with limited resources. Traditional supervised restoration ensures high control over image quality but requires specialized personnel and long timeframes, generating significant economic and operational burdens. SCAs, by enabling automatic color correction with minimal intervention, reduce labor costs, accelerate workflows, and minimize technological and human resource consumption.

The restoration of "The Funeral of the Bombing of Piazza della Loggia in Brescia" illustrates the demands of traditional digital restoration, including extensive manual intervention and technical expertise. Conversely, the unsupervised restoration of "La Lunga Calza Verde" shows that SCAs can deliver high-quality results while simplifying workflows and reducing costs, allowing smaller institutions to preserve works otherwise inaccessible.

From a sustainability perspective, SCAs support economic, social, and technological sustainability: economically, by reducing reliance on costly software and specialists; socially, by enabling broader participation including students and emerging technicians; technologically, by offering open-source algorithms adaptable to institutional needs.

In conclusion, automated, unsupervised methods reconcile quality and sustainability in film restoration. While supervised methods remain essential for works of high aesthetic or technical complexity, SCAs provide an effective, cost-efficient, and environmentally friendly alternative. Their use demonstrates that operational speed can be combined with acceptable final quality.

7. Conflict of interest declaration

All authors declare that they have no conflicts of interest.

8. Funding source declaration

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10. Short biography of the authors

Giovanni Vanoglio - He is a professional photographer and Research Fellow at the Department of Computer Science of the University of Milan, where he contributes to a PRIN project dedicated to work and industry museums, with a focus on the conservation, restoration and reuse of audiovisual archives. Alongside his research, he has developed a significant teaching activity in light design, color, design and communication at Fondazione Clerici, Poli.Design and Poliestetico in Milan.

Alessandro Rizzi - Alessandro Rizzi is a Full Professor at the University of Milan's Department of Computer Science, where he teaches multimedia, colorimetry, and film restoration. Head of the MIPS Laboratory, his research since 1990 has focused on digital imaging, particularly color, HDR, photography, and perceptual aspects of imaging, interfaces, and lighting.

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The illusion of color: the chromatic interactions of Josef Albers in 3D spaces

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ABSTRACT

Josef Albers, a central figure in the evolution of 20th-century color theory, profoundly influenced both the artistic and scientific understanding of chromatic interactions. In his work, particularly *Interaction of Color* (1963), he explores how colors affect one another and how these interactions can alter visual perception. Albers believed that color was not an intrinsic quality of an object, but rather a relative phenomenon, whose perception is shaped by context and environmental conditions. This principle of chromatic relativity was illustrated through a series of practical exercises demonstrating how the same color can appear different depending on the surrounding colors, emphasizing the importance of chromatic contextualization. This perspective opens interesting possibilities in three-dimensional design, where Albers' theories can be applied to influence spatial perception. Delving into his ideas within three-dimensional environments presents an engaging experimental challenge. Through immersive virtual simulations and real-time rendering, it is possible to explore the effects of certain chromatic interactions described by Albers on visual perception of space. Applying Albers' theories to 3D environments is not merely a theoretical exercise, but carries significant practical implications for architectural design, as it addresses the perceptual manipulation of space through the interaction of light and color. Reflecting on Albers' theories using advanced technologies allows for a deeper understanding of his work and the creation of visually stimulating and perceptually dynamic spaces.

KEYWORDS Josef Albers, 3D space, VR, Simultaneous Contrasts, Afterimage

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1. Introduction

The 20th century was marked by intense intellectual ferment that led to conceptual revolutions and new practical frontiers in fields such as art, architecture, design, and visual perception. In these disciplines, as well as in psychology, Gestalt theory –originating in Germany in the 1920s– provided a crucial contribution to the understanding of perceptual processes. This theory, focusing on the organization and interpretation of visual perception, shifts the emphasis from individual elements to the overall configuration, based on the principle that “the whole is greater than the sum of its parts” (Koffka, 1935). As a result, an image or form is not a mere aggregation of visual components, but generates more complex perceptual experiences. Movements such as the Bauhaus, developed at the intersection of art and industry, proposed an integrated vision of the creative disciplines, redefining the relationship between form and function. Color theory played a central role: the contributions of figures such as Johannes Itten and Josef Albers introduced radical approaches and experimental explorations of color. Although their approaches diverged –Albers emphasizing practice and relational perception, Itten developing a more spiritual and symbolic use of color– their dialogue at the Bauhaus provided a fertile ground for the subsequent evolution of modern color theory. These contributions extended beyond the two-dimensional realm and influenced applied arts and architecture, opening new possibilities for the perception and use of color in space.

Albers occupies a pivotal role in rethinking chromatic perception in terms of interaction. Through his teaching at the Bauhaus, Black Mountain College, and Yale, he developed a hands-on approach to color, privileging “practice before theory” (Albers, 1963). His work *Interaction of Color* challenges the perception of color, shifting it from its intrinsic qualities to its relational nature. The book, composed of a series of practical exercises, explores the mutability and deceptions of chromatic perception. For Albers, color is not a fixed and stable characteristic but a phenomenon subject to variation depending on context (Weber, 1988). His theory of “chromatic relativity” departs from static color models such as Goethe’s color wheel (1970), asserting instead that colors are perceived in a “continuous flow,” where the same color may appear lighter, darker, warmer, or cooler depending on its combinations. Albers’ approach resonates with the principles of Gestalt theory, which he himself references (Albers, 1963). The optical illusions produced by his experiments demonstrate that the perception of color depends on its interaction with other colors, as well as with shapes and positions, creating visual configurations that alter perceptual experience

(Arnheim, 1974). Albers thus highlights how the perception of color is closely linked to environmental conditions, generating what he describes as a “discrepancy between physical fact and psychic effect” (Albers, 1963; Albers, 1969).

In the field of architecture, Albers’ work offers compelling insights, despite having focused primarily on color applied to flat surfaces. Contemporary architects such as Le Corbusier and Luis Barragán explored the use of color in architecture not only for aesthetic purposes, but also for functional and plastic effects. Le Corbusier used color to modify spatial perception and guide attention (Morgado, 2020), while Barragán integrated color into the architectural structure to evoke emotion and transform space (Ambasz, 1976).

Albers’ theories on chromatic interaction have thus proven applicable even in spatial design, despite originating from two-dimensional considerations (Serra Lluch, 2023). This contribution aims to explore the three-dimensional effects of the chromatic interactions described by Albers, experimenting with the transposition of these theories into architectural contexts. The use of immersive technologies, such as virtual reality, allows for the manipulation of color in controlled environments and the study of perceptual effects of chromatic interactions from within architectural spaces.

2. Simultaneous contrasts and post-images

In the experimental explorations of color interaction conducted by Albers, numerous visual phenomena, effects, and illusions are referenced and interconnected – some of which were already known or studied by other theorists of the time. Many of the cases discussed relate to two closely connected concepts, according to the author: simultaneous contrast and afterimage.

Within the divergence between physical fact and psychic effect emphasized by Albers, simultaneous contrast is a phenomenon that occurs when multiple colors placed next to each other appear to influence one another, making them seem “different from what they actually are.” This is rooted in the human eye’s tendency to interpret visual (not only chromatic) information holistically and in relation to its context. For instance, a neutral gray may appear slightly bluish when placed next to an orange color, or yellowish when adjacent to purple (fig. 1). This is a clear example of how color perception is relative and unstable (Albers, 2013). The scientific explanation of this phenomenon lies in the way retinal cones, responsible for color perception, (inter)act. These cones are divided into types, each sensitive to a specific wavelength of light. When observing multiple colors, the cones are activated depending on the

amount of light reflected, but color perception is also influenced by the activation of neighboring cones. In simultaneous contrast, this interaction among cones in different areas of the retina leads the brain to emphasize chromatic contrasts to heighten visual differentiation, causing colors to appear different from their physical reality (Goldstein, 2017).

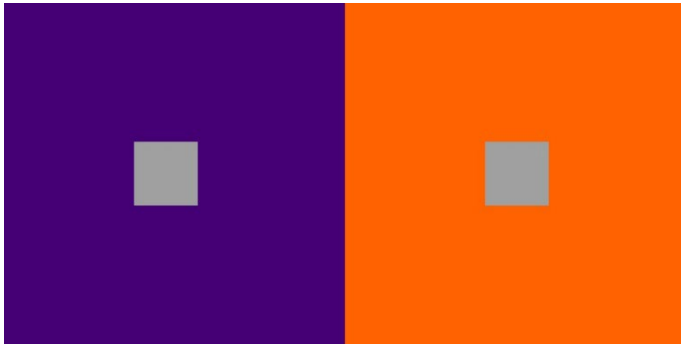


Fig. 1. In this reproduction of one of the exercises, the same neutral gray may appear more bluish or yellowish when placed against an orange or purple background, respectively.

Also related to the behavior of retinal cones, the afterimage is a phenomenon that occurs when, after staring at a color for a certain period of time, a residual image of its complementary color continues to be perceived—even after shifting one's gaze to a neutral surface. This effect is caused by temporary fatigue of the cones: when an intense color is observed, the cones that respond to that specific wavelength become overstimulated and less sensitive. As a result, when the gaze shifts to a neutral surface, the cones sensitive to the complementary color become more active, causing the appearance of the afterimage (Pinna, 2010). In one of his exercises, Albers invites the viewer to focus intently on a red circle (against a black background) for several seconds before shifting their gaze to a white disc, upon which a residual green image—the complementary of red—will briefly appear (fig. 2). This also highlights how color perception is not a passive representation, but rather a dynamic psychophysiological process.

An important consideration was raised regarding the critical relationship Albers establishes between simultaneous contrasts and afterimages, which he often refers to interchangeably, as though they were the same phenomenon (Lee, 1981). Clear differences exist in both spatial and temporal terms: simultaneous contrast occurs immediately and regardless of whether the gaze is moving or fixed, whereas afterimages are only visible after a period of focused attention on a color, followed by a shift

to a neutral background. Nevertheless, both phenomena remain interconnected and can, in various ways, help explain the underlying mechanisms of many chromatic effects and illusions that result from color interaction.

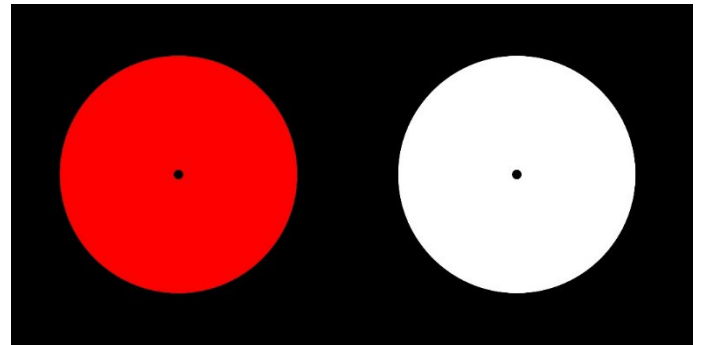


Fig. 2. Authors' reproduction of an exercise proposed by Albers to explore the phenomenon of afterimage.

3. Chromatic interactions in virtual reality: Albers's Chambers VR

The three-dimensional experimentation on the chromatic interactions described by Albers stems, first and foremost, from a necessary selection of specific exercises he proposed, in order to transpose them effectively into a virtual environment. In this sense, the various categories of effects and phenomena he described were carefully analyzed to identify those experiments that could be meaningfully and interestingly translated into three dimensions, potentially offering new insights. This selective process was driven by the increased complexity inherent in 3D transposition: it became clear from the outset that some of Albers' exercises could hardly be rendered in spatial terms without losing effectiveness or adding little beyond what could already be experienced on paper in two dimensions.

One of the strengths guiding this research lies in the ability, within a virtual environment, to control and isolate color interactions more effectively, eliminating interfering elements that in physical reality can at best be reduced, but not entirely removed. Lighting, shadows, and the material qualities of surfaces can be freely defined to best convey the perceptual experience. For instance, in the immersive experiences described below, the user has no corporeal presence in the scene: they can move and interact immersively, yet remain invisible, thus avoiding any chromatic interference with the environment.

Similarly, the three "Albers chambers" are designed to be isolated from one another. For this purpose, a teleportation system was implemented in the VR environment to allow users to move between rooms without transitional spaces or doors, which might compromise the experiment.

Nevertheless, the virtual experiences devised here are digital simulations of physical phenomena; they can mostly approximate the real effect, but with inherent limitations stemming from the nature of the medium itself. These divergences from reality, however, can be deliberately exploited to achieve results that would otherwise be unattainable –such as the total elimination of shadows within the workspace.

The design of the chambers was intentionally kept as essential as possible, directly inspired by the simplicity of Albers's original exercises, where basic shapes, colors, and spatial relations generate perceptual effects. The goal was to transpose these principles from the bidimensional plane into space, without unnecessary complexity. In particular, the second chamber openly draws inspiration

from Barragán's plastic and chromatic strategies, further grounding the design in architectural practice. Three immersive experience rooms were therefore developed as part of a single, interconnected experiment entitled *Albers's Chambers VR*. Some of them directly reference the plates featured in *Interaction of Color* (2013), while others present alternative versions of the processes outlined in certain chapters. The methodology for creating the Albers rooms began with a rapid concept phase, using hand-drawn sketches to evaluate possible 3D interpretations of the experiments. The project then moved directly into NURBS-based 3D modeling using Rhinoceros 7 (fig. 3). The completed experience-rooms were then converted into mesh surfaces for the next stages and imported into Unreal Engine 5.3, the platform through which the VR experience described below was developed.

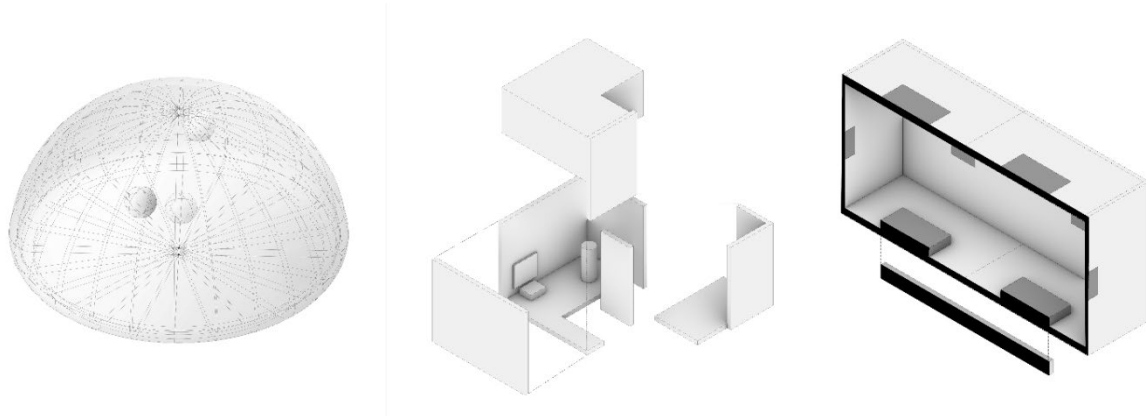


Fig. 3. The models of the three Albers's chambers elaborated for the subsequent experimentation in virtual reality

The first room (fig. 4) takes as its reference the theme of color subtraction, focusing on the interaction between the elements and the background on which they are displayed. The original exercise involved the use of three different red samples placed against varying backgrounds –either matching or contrasting with the subject colors. Albers observed that when the background changes, the red samples tend to emphasize their differences rather than disappear entirely, even when the background matches one of the three reds. Building on this idea, a space was designed in which three differently shaded red spheres float in motion, allowing users to dynamically explore the effects of background color variation on the scene's objects. The room was conceived as uniform as possible, enabling free movement without excessive interference from the user's own shadow or form. An initial idea proposed a monochromatic spherical environment, but this shape restricted user movement across its base. Therefore, it was replaced with a dome measuring 12 meters in diameter, smoothed at the base where it meets

the ground. This form –often used for applying HDRIs in rendering scenes– offers a wide horizontal plane for movement, while minimizing the shadows on the backdrop. Some light shadows remain visible to aid the user's spatial orientation. The three spheres were animated to float slowly and steadily within the empty space, occasionally overlapping to create temporary color interactions. The dome's surface was programmed using a typical Unreal Engine blueprint so that the user, by clicking a button, can interactively change its color –cycling from the initial white to each of the three reds, and finally to a fourth, different red tone. Instructions on how to interact with the scene are provided via a black holographic text placed at the edge of the environment, at the user's starting point, designed to be as unobtrusive as possible. Additionally, visual contrast and shadows were minimized by manipulating the observer's digital vision using a *PostProcessVolume*, enhancing the visibility of interactions between the spheres and the background.

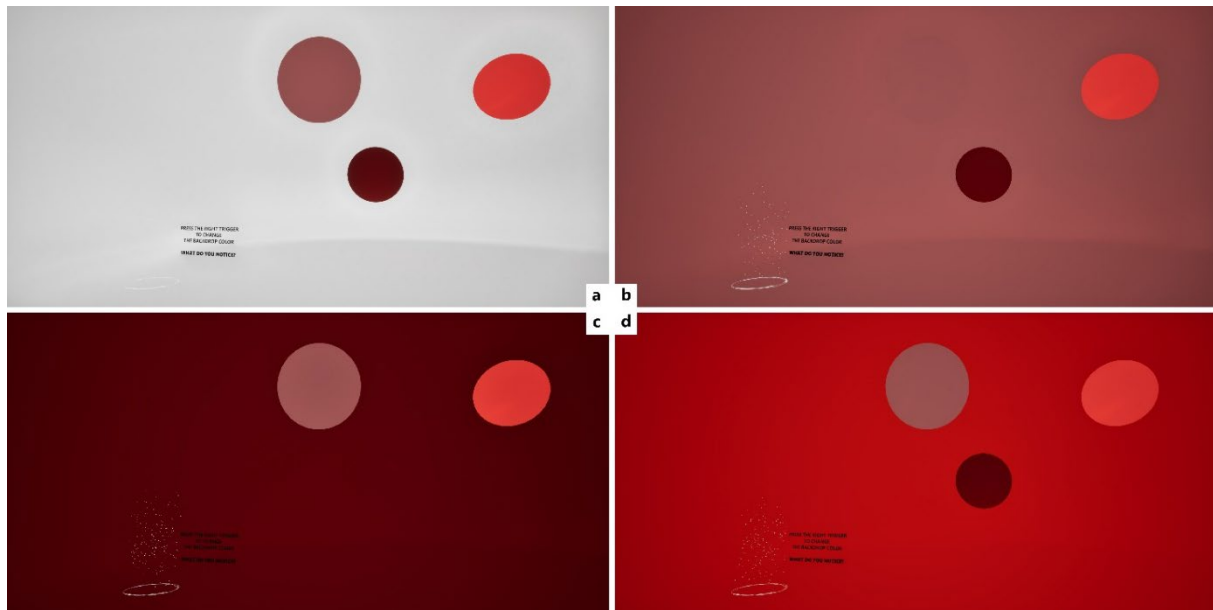


Fig. 4. Albers's First Chamber. The spheres, visible against the white background (a), blend into the background when it matches their color (b, c), and appear altered when the dome shifts to a fourth tone different from the others (d).

Albers's second chamber (fig. 5) takes inspiration from the plates related to the afterimage effect (VIII-1 / VIII-2), seeking to recreate the same phenomenon within an architectural environment. To achieve this, the design draws on the iconic plasticity and use of color characteristic of Luis Barragán's work, creating a square-based space populated by simple, essential volumes. The main walls, ceiling, and floor were rendered in nearly neutral tones, while the other elements were colored with stronger, more saturated hues –better suited to producing pronounced afterimage effects than more muted tones.

In the initial phase, as in Barragán's architecture, the surfaces were given a pronounced materiality, using rough concrete, plaster, and reflective materials. However, the same experiment was later repeated with these material qualities removed, as they clearly interfered with color

perception and interaction within the space. In this version, the chamber is softly and naturally lit from a skylight, creating an environment free of harsh contrasts.

Based on the hexadecimal codes of the selected colors, complementary hues were calculated to create new materials applied to the scene. Each of these was also rendered in a white version, retaining only the original surface texture, in order to allow the retina to project the afterimage onto it. Once again, the user is allowed to move freely within the space and is prompted –via another hologram– to focus intently on a specific point of the scene for at least 30 seconds before pressing a button. This action switches the environment from its complementary color version to the white one, enabling the user to perceive the original chamber as an afterimage.



Fig. 5. Albers's Second Chamber, in its different color versions: complementary (a), neutral (b), and original (c), which is the way the chamber should look like in its post-image

The third experience-room designed (fig. 6) recreates, in 3D, the theme of inverted backgrounds, drawing on the forms of plate VI-4 and the colors of VI-3. These two exercises illustrate how different backgrounds affect the perception of a third, identical color, which appears as two distinct hues depending on its surrounding context.

In this case, a large, single space was designed, measuring 20×10×10 meters, softly lit with artificial lighting to avoid harsh shadows. Visually, the room appears as the juxtaposition of two cubic spaces joined through one face; this is further emphasized by the two distinct colors (yellow and purple) that define the walls, ceilings, and floors of

each half. Squares of a third color are embedded in each surface, and on the floor plane, they become two separate, disconnected platforms.

The user is teleported onto one of the platforms and can observe the effects produced by the background colors on the perception of the third tone. As in Albers's original exercise –where a strip of paper was used to connect the two smaller squares and demonstrate that they were in fact the same color– the user here is given the option to press a button, which causes a bridge to appear or disappear, visually connecting the two platforms that initially seemed to have different colors.

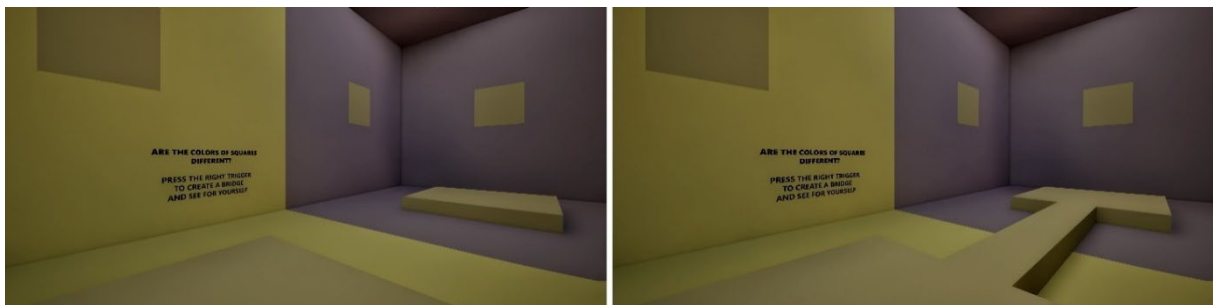


Fig. 6. Albers's Third Chamber. The squares/platforms, seemingly of different colors (left), are in fact the same color, as demonstrated by the activation of the connecting bridge (right).

4. Conclusions

The three virtual experiences presented in this contribution aim to reinterpret Albers's exploration of color interactions in a three-dimensional key, attempting to transform some of his exercises into dynamic and interactive virtual experiments. In this regard, the potential of VR allows for engaging and innovative demonstrations and analyses of specific phenomena, enabling the construction of digital laboratories that are controlled, expandable, and constantly evolving. In the future, the Albers's Chambers described here could be further developed through the addition of new experience-rooms.

In the first chamber, by changing the color of the dome, the visitor observes how some spheres seem to disappear entirely and reappear elsewhere, or even shift in hue; chromatic interaction is intensified by both the objects and the user, who generate ever-changing configurations (and overlaps) of colors. The second chamber introduces two distinct approaches to the afterimage effect, with slightly different results compared to the original exercise: in the material version, it is the surface qualities –along with the light and shadow of the plastic forms– that tend to dampen the phenomenon, especially along edges and corners where shadow variation is greatest. In the immaterial version, the effect is clearly more successful, although still

subject to light-related interferences, and remains perceptible, though less intense than on paper. In this respect, it is essential to consider how the colors themselves –due to light reflection– interfere with chiaroscuro, creating apparent colors that alter the perception of surface tones (Calisi, 2013).

The third chamber allows the user to perceive how adjacent backgrounds alter the perceived color of the squares, which appear as two distinct hues –until the activation of the bridge/connector, which immediately cancels the illusion by enabling a direct comparison of their actual identity. In all three cases, albeit in different ways, it becomes evident how the third dimension adds further layers of complexity to be considered, such as the forms and shadows of the objects; these inevitably influence scene perception and may potentially distort the outcome of the exercise if not properly managed.

The developed scenarios represent only three out of many exercises that could be reimagined in three-dimensional experimental form. Furthermore, starting from the same plates and exercises, numerous other ways of reconstructing similar experiences on these themes are conceivable. It should also be stressed that perceiving color through electronic devices inevitably differs from the

sensation conveyed by pigments and materials in real space; this limitation must be acknowledged when validating virtual experiments against physical reality, although it also opens reflections on possible calibration tools bridging the two domains. In this sense, the Albers's Chambers VR project highlights the potential –though not without limitations– of using virtual laboratories to engage with topics such as color interaction in a dynamic, interactive, and immersive way, whose future developments may further enrich the analysis and narration of the complexity behind perceptual phenomena.

5. Conflict of interest declaration

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The black background in advertising posters: some examples from the early decades of the 20th century

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ABSTRACT

At the beginning of the 20th century, an important innovation appeared in European advertising posters. Until then, the background of a poster appeared as a logical consequence of the scene depicted, reflecting its compositional and chromatic characteristics. This was the case, for example, in the posters of Jules Chéret, Henri Toulouse-Lautrec, Alfons Mucha, Adolf Hohenstein and others. Leonetto Cappiello, an artist from Livorno who had moved to Paris, created an advertisement for Swiss chocolate 'Klaus', in 1903, radically revolutionising the concept of product communication. The artist introduced so many new features that the Chocolat Klaus poster is considered a real turning point in his career, which he described as 'the second stage of my evolution'. Cappiello was the first to realise that advertising posters had to stand out from the monotonous greyness of the wall on which they were displayed, imposing themselves on their surroundings and creating a 'visual shock' for the observer. The advertising poster must have a basic design and simple graphic language; its bright colours ensure that the observer is not distracted in the few moments when their attention is focused on the poster they are looking at. In the following years, Leonetto created numerous commercial posters applying the same compositional principles: figures drawn with simple lines, bright and contrasting colours, characters with cheerful and smiling expressions, and minimal text, most often limited to the name of the product being advertised. Above all, everything stands out against a black background. Few artists sporadically used black backgrounds in their posters during those years, for example, Marcello Dudovich and Leopoldo Metlicovitz; this limited use of dark backgrounds continued until the second decade of the 20th century, when Leonetto Cappiello's posters, now well known, widespread and appreciated, became a model and source of inspiration for other artists. By now, the black background solution was being used by many other important poster artists, including, for example, Giuseppe Magagnoli, known as MAGA, Achille Luciano Mauzan, Plinio Codognato and Severo Pozzati, known as SEPO, in Italy, and Jean d'Ylen, Adolphe Mouron, better known as Cassandre, Charles Loupot and Paul Colin in France. In this short article, we aim to show how Leonetto Cappiello's innovations, particularly the use of a black background in advertising posters, were so successful that they were adopted by the most important poster artists of the early 20th century within a few decades.

KEYWORDS Posters, Advertising, Black background, Leonetto Cappiello

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1. Introduction

Around the mid-1800s, incredible advances were made in printing techniques; the invention of chromolithography made it possible to reproduce large-format colour images, imitating the colours of tempera or oil paintings [1]. At the same time, the commercial world became aware of how much massive advertising could spread awareness and enjoyment of a material product, an event or even a social or political idea. The 19th century was also the golden age of the wall poster; the visual arts, painting and engraving merged with mass publishing, revolutionising the traditional concept of 'art', which was now destined for street billboards or to enter homes in the form of posters, but above all to imprint itself in everyone's minds through iconic images. The streets of cities became a sizeable open-air museum [2], where street art, with posters affixed to walls as its protagonists, gave numerous artists, known as 'affiliates' in French, the opportunity to gain notoriety and fame. Fin de siècle Paris saw the emergence of artists such as Eugène Grasset, Jules Chéret, Henri de Toulouse-Lautrec, Alfons Mucha and others. At the beginning of the 20th century, Leonetto Cappiello, a young artist from Livorno, debuted on the Parisian art scene. Within a few years, he managed to gain undisputed prominence.

2. The background of the posters: from exuberance to synthesis

At the end of the 19th century, the Parisian artistic scene was a melting pot of ideas, innovations and experiences. In the field of poster design, new graphic solutions were being experimented with to give greater prominence to the message to be communicated. Several salient elements began to emerge that would make up the poster: the main image, designed to strike and attract the viewer; the background, against which the subject stands out; the logo or brand, which identifies the product; any slogan, which should entice the customer to purchase and consume; and, lastly, helpful information, such as the address, location and place of sale. Although the central part of the poster is the focal point of the viewer's attention, the background against which the scene stands out is no less important. While retaining its identity and graphic characteristics, the poster's background must complement the central image, which plays the leading role and is essential for enhancing, emphasising or creating contrast with the main subject. The great French affiliates interpret and combine the components of the poster with imagination and diversity. In Eugène Grasset's sober Art Nouveau style, the backgrounds are sometimes monochrome, sometimes streaked with colour or covered with tree branches or floral compositions. Jules Chéret

creates backgrounds with varied nuances in a multiplicity of chromatic transitions of shades of colour ranging from deep blue to light blue, then dissolving into the white of the paper. For Alfons Mucha, the background is almost as important as the subject of the poster, a riot of colours, combinations created with elaborate mosaics, very fine pieces, studied down to the smallest detail (Scalzo 2022a, pp. 884 ff.); or he invents precious phytomorphic compositions rendered in great detail. Henri Toulouse-Lautrec sought graphic synthesis, the essentiality offered by a monochrome background, whether blue, yellow, ochre or marked by a few hints of settings, most often theatrical backdrops. In 1896, Jules Chéret was among the first to propose a dark background for posters; he created two posters for Loïe Fuller, in these cases, however, the black background is not a chromatic choice but a representation of reality: the show takes place in the darkness of the theatre, where the dancer twirls in the darkness of the stage in a dress made of coloured and fluorescent veils, illuminated by narrow beams of light.



Fig. 1 - Jules Chéret, *Redoute Etudiants*, 1894.

Fig. 2 - Alfons Mucha, *La Plume*, 1897 ca.



Fig. 3 - Henri Toulouse-Lautrec, *May Milton*, 1895.

Fig. 4 - Jules Chéret, *La Loïe Fuller*, 1896.

3. Leonetto Cappiello: his Parisian debut, innovation

In 1898, a young artist from Livorno arrived in the French capital: Leonetto Cappiello. His Parisian debut saw him produce a series of caricatures of famous people; unexpected success propelled him into the world of advertising, where he made a name for himself in just a few years. Following in the footsteps of Chéret and Toulouse-Lautrec, whom he greatly admired [3], he introduced a modern, incisive and concise language with essential graphics to the world of 'affichés', which was decidedly detached from the, albeit appreciated, but excessive 'decorative ornamentation' that characterised contemporary posters (Scalzo, 2022b, pp. 884 ff.); Cappiello's style was almost an 'expressionist trend far removed from the Art Nouveau style' (Wlassikoff, 2008, p. 32). The Livorno artist's first posters are enlarged caricatures in which he already shows his mastery of layout by applying one of his fundamental principles: a simple, monochrome background against which the central character stands out easily; 'he initially used various styles, particularly influenced by Lautrec and Chéret, from whom he adopted the use of a solid-colour background' (Hollis, 2005, p.13). This concern for the legibility of the poster sets him apart from most of his contemporary poster artists, who seem more interested in details than in efficient and concise communication. Other fundamental principles of Cappiello are legibility and attribution; to be legible, the poster must be simple: clear elements and characters on a dark background, or vice versa; the poster is designed to be placed on the street, in whole light, seen quickly and from a distance [4]. It should never be in harmony with its surroundings; on the contrary, it should stand out in total opposition. It should also create a kind of surprise effect, an essential condition for any advertising that is to be effective. The colours used should be those that make the most significant impression on the retina, 'but what makes a good poster above all is a line, what he calls the arabesque, a synthesis of the idea: it is the line that we must seek and give secondary importance to colour and details, which should only highlight and embellish. To be effective, the passer-by must immediately associate the poster with a brand: it is, therefore, necessary to invent a character, a grotesque animal or something else that, through its repetition, will be inextricably linked to the product' (Weill, 1984, p. 126).

4. Leonetto Cappiello's breakthrough: the black background

Although Cappiello had already created some advertising posters (the first for the magazine Frou-Frou was in 1899),

1903 was the year of his breakthrough. One night, posters for Chocolat Klaus appeared on the walls of Paris: a woman dressed in green was riding a red horse; the words at the bottom, in large letters, were yellow, the slogan was blue, and everything was on a black background.



Fig. 5 - L. Cappiello, *Chocolat Klaus*, 1903.

Fig. 6 - L. Cappiello, *Katabexine*, 1903.

A few considerations are necessary: First, the advertised product does not appear in the poster; furthermore, the deliberate contrast of pure colours spread evenly across the surface highlights the dissonance of the colour planes; the most significant innovation is the use of a black background. As a result, the painted image emerges powerfully from the dark background, standing out clearly to the observer; the letters of the words 'Chocolat Klaus', in a dazzling chrome yellow, light up against the dark background. Cappiello opts for a female figure as a testimonial, 'the woman is first and foremost seductive, taking on the features of famous actresses who seem to have stepped out of a music hall: corset at the waist, low neckline and smiling' (AA.VV., 2020, p. 14), the girl portrayed has synthetic features, a legacy of his debut as a caricaturist, the woman and the red horse are something crazy, halfway between a dream and a fairy-tale setting and, above all, they have no logical connection with the product being advertised; 'the image is dissonant and illogical (...) with its movement it accompanies the passer-by and seems to jump out to chase him, call him, force him to turn around' (Monti-Matucci, 1985, p. 18). The artist should not give a scrupulous representation of the product, but rather "the idea": 'With Chocolat Klaus, Cappiello has virtually defined a new concept in poster design: a bold approach that breaks through the barriers of traditional Victorian moderation and penetrates directly into the viewer's subconscious to evoke images that remain indelibly associated with the advertised product' (Rennert, 2004, p. 16). In his compositions, Cappiello pays particular attention to the search for what he calls 'arabesque', a

word to which the artist attributes a special meaning: 'arabesque' is a harmonious organism, the essential structure of the composition, 'in a sense its backbone' (Viénot, 1946, p. 57), the decorative element that connects the different components, design and colour, to give them 'form', reason and concreteness. Also, in 1903, Cappiello created other posters using a black background: Amidon au Chat - Hoffmann and the effervescent tablets Katabexine. Here, too, the advertised product is almost invisible, the entire poster is occupied by the elegant, sinuous figure of a woman in a brightly coloured dress: red and fuchsia, with a green hat, all surmounted by yellow lettering.



Fig. 7 - L. Cappiello, E.&A. Mele, 1903.



Fig. 8 - L. Cappiello, Cri-staux Iodes Proot, 1905.

The poster Leonetto Cappiello created for the Italian market for the important fashion store Mele in Naples dates from 1903. This time, however, the image depicted is not unrelated to the type of product being advertised: an elegantly dressed couple stands out against a dark grey background, creating a slight colour contrast with the black evening suit worn by the man. The woman's dress stands out even more: a riot of colours, a red dress, a yellow hat with green feathers, a beige ostrich feather boa, and yellow lettering stand out against everything. The path was now clear, and in the following years, Cappiello produced numerous posters, some with a black background, becoming a leading figure in the art of communication through images; his innovative ideas for advertising graphics began to influence the creations of numerous contemporary poster artists and subsequent generations. 'Black, a colour previously little used in poster design, gained a place of honour (...) and Cappiello never abandoned it completely' (AA.VV., 1981, p. 17); in the years that followed, one of the artist's most iconic posters was the one for Cristaux Iodés Proot in 1905, where

Cappiello associated the slogan 'to live a long life' with a hundred-year-old man with a long white beard, wearing a tight-fitting yellow suit, standing on a ladder. He also worked for Spanish companies. In the poster for 'Coñac del Caballo Verde', also from 1905, Cappiello repeated, as he had done for Chocolat Klaus, a highly imaginative pairing: a red-haired Amazon in a yellow costume riding an unlikely green steed, all against a black background with yellow lettering, a lively composition that remains etched in the mind of the observer.



Fig. 9 - L. Cappiello, Coñac Caballo Verde, 1905.

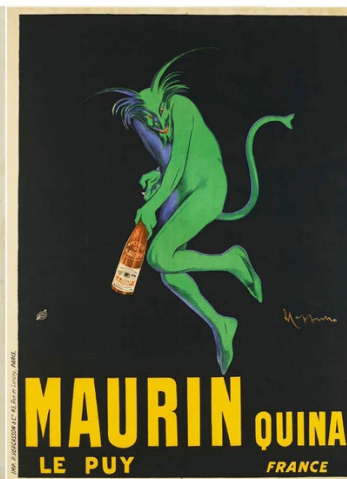


Fig. 10 - L. Cappiello, Maurin Quina, 1906.

In 1906, Leonetto Cappiello created a poster printed by Vercasson 6] for 'Maurin Quina Le Puy' [7]; affectionately known as 'Il Diavolo Verde' (The Green Devil), it is a surprising image that combines something sinister and ironic, managing to be both fascinating and compelling. Histrionic and sly, the green devil, highlighted by purple shades, is depicted in the act of uncorking a red bottle. It is no surprise that this poster is one of the most memorable icons of Cappiello's visual legacy.

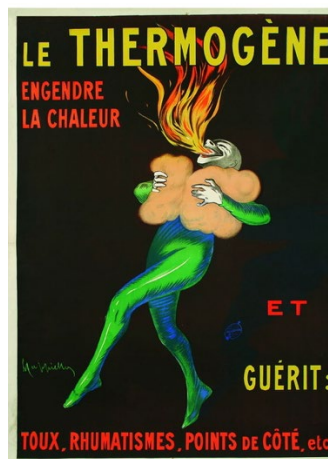


Fig. 11 - L. Cappiello, Thermogene, 1909.



Fig. 12 - L. Cappiello, Isolabella, 1910 ca.

Leonetto is defined as the inventor of the 'poster brand' (Villari, 2008, p. 23) because he manages to create a strong connection between the brand and the image created, so much so that the company Thermogène specifies: 'Ask for the fire-breathing Pierrot' (AA.VV., 1981, p. 17), and not 'Ask for Thermogène', as the image created by Cappiello wins with the power of conviction and definitively imposes itself on the consumer. The Pierrot of Thermogène becomes an iconic and long-lasting advertisement, never going out of fashion as a classic, which will last from 1909 for over 50 years. The choice of an iconic mask from the Italian commedia dell'arte, Arlecchino, to advertise the products of the Isolabella company between 1909 and 1910 was perhaps suggested by the Italian nature of the product being advertised. However, here, too, Cappiello surprises and amazes: the subject is an 'arlecchina' (a female Harlequin), a slender female figure with red hair and vermillion lips, dancing sinuously among the bottles, an irrational image on a conscious level, but one that remains unmistakable on an emotional and unconscious level. In an era of fast-paced rhythms, passers-by no longer have time to stop and look at advertising posters and, therefore, no longer read the text. Cappiello's posters offer us images without superfluous embellishments, which, in their synthesis and essentiality, manage to strike, surprise and attract attention at all costs.

5. The spread of the black background on Italian posters

After 1903, Leonetto Cappiello became a leading figure in the art of communication through images; his innovative ideas for advertising graphics began to influence the work of numerous contemporary poster artists and subsequent generations.

The dark background, previously little used in poster design, gained a place of honour, especially after around 1910. Cappiello never completely abandoned it [8]: 'The background of many of his posters is solid black, which isolates them from the other posters on the fence, and there are many foil strips that highlight the violent colours...' (AA.VV., 1981, p. 17). The dark background solution began to spread among poster artists, especially Italian ones, who sensed its graphic potential. At the beginning of the 20th century, Plinio Codognato from Verona created a poster for 'Vermut Bianco Cattarozzi', but the black background seems to be more due to the setting of the scene, which appears to take place at night under the light of a street lamp, than to any real intention on the part of the author to use a dark background. Some time ago, there was a dispute over who was the first to use a black background in posters: 'The search for synthesis

led Codognato to use a black background for numerous posters. The attribution of temporal primacy between the Veronese artist and Leonetto Cappiello is disputed' (Martinelli, 2011, p. 110); but looking closely at the chronology and style of the works, we can only assign primacy to the Livorno artist. In the poster for 'Rabarbaro Cillario Roma' from around 1915, Codognato presents a scene with a black background set among the ruins of the capital, between the Colosseum and the three columns of the temple of Castor and Pollux in the Forum: a bottle of liqueur dressed as a charioteer drives a chariot pulled by two rearing horses, red like the chariot. These colours are decidedly unusual but destined to remain in the viewer's memory. This is the so-called 'Rosso Codognato' (Martinelli, 2011, p. 112), which the artist would use in many of his posters.



Fig. 13 - P. Codognato, Cattarozzi, 1900 ca.

Fig. 14 - P. Codognato, Cillario, 1915 ca.



Fig. 15 - P. Codognato, Motocicli Douglas, 1915.

Fig. 16 - L. Metlicovitz, Marmellate Fede, 1927.

A highly evocative poster by the Veronese artist is the 'Motocicli Douglas' (Douglas Motorcycles) from 1915: against a black starry sky, like a flaming comet, stands out the centaur riding a motorcycle rendered in shades ranging from yellow to intense red; at the bottom are the logo and lettering in bright green. Cappiello was the first to draw a fantasy subject to advertise an article, creating a sort of synonym for the product itself (e.g. Thermogène ointment) or drawing inspiration from history by associating the product with a famous person, a deity, a mythological subject or a king. Leopoldo Metlicovitz drew on Italian literature, adopting perhaps one of the most representative icons of Italian tradition for the 'Marmellate Fede' poster: Pinocchio. A fine and refined poster artist, historical graphic designer for the Ricordi company in Milan and creator of famous posters for plays and films, Metlicovitz gracefully and humorously depicts the puppet in his characteristic red and white outfit, eating jam from a jar with a spoon, while a small dog of the same colours licks the drops of jam that have fallen on the floor (Panzeri, 2014, p. 76).

becomes the protagonist, from which a few elements emerge, the face, hands and red hair of a woman intent on writing on some sheets of paper; the poster is completed at the bottom by the logo and explanatory text. One of Dudovich's most iconic posters is undoubtedly the one for 'Vermouth Bianco' from 1920, a successful combination of the black background and the elegant white dress of the girl, which widens towards the bottom to include the brand name 'Martini & Rossi - Torino'. Jean d'Ylen took over from Vercasson as artistic director when Cappiello, with whom he had collaborated, terminated the 'restrictive contract' (Forni, 2008, p. 79) that bound him to the Parisian printer [9]. Jean d'Ylen inherited his master's style, numerous sketches and notes that Leonetto had left at Vercasson; in fact, the poster for 'Gran Vin Blanc' clearly shows the master's established stylistic features: against a black background, a ruddy Bacchus happily rides a bunch of white grapes.



Fig. 17 - M. Dudovich, Stufa Weinhausen, 1906.

Fig. 18 - M. Dudovich, Inchiostri Rapid, 1906.

Another example of 'Art Nouveau style' is the poster, from around 1906, by Marcello Dudovich for the 'Weinhausen Stove'; the scene, against a dark background, shows an elegantly dressed young woman sitting to warm herself and an elderly, distinguished gentleman (dressed in black, so that he blends into the background) who reveals her bare shoulder, evidently because of the intense heat. These small, almost imperceptible gestures perfectly convey the scene depicted. In Dudovich's posters, 'the images portrayed are almost always those of elegant, wealthy women... and authoritarian, self-assured gentlemen belonging to the ruling class' (AA.VV., 1985, p. 43). For 'Inchiostri Rapid', Dudovich created a poster, dated 1906, which is highly synthetic: the black background, reminiscent of the product being advertised,



Fig. 19 - M. Dudovich, Vermouth Martini, 1920.

Fig. 20 - Jean d'Ylen, Gran Vin Blanc, 1920.

Already the representative in Italy of the publisher Vercasson, Giuseppe Magagnoli founded MAGA, which quickly became the most important advertising agency in Italy; he collaborated with some of the most famous poster artists, such as Luciano Mauzan, Severo Pozzati and Marcello Nizzoli. In Magagnoli's 1921 poster 'Cordial Campari', the protagonist is a Pierrot greedily drinking the liqueur; yellow (the colour of the advertised product) predominates in the lettering, and the light comes from below as if the scene were taking place in theatre stage. Maga established a long and fruitful professional partnership with Achille Luciano Mauzan. In his 1921 advertisement for 'Anisetto Alberti', the author drew a strange medieval knight in unlikely green armour, depicted crouching down to open a bottle with the tip of his sword. Severo Pozzati, known as Sepo, created a poster for Maga in 1920 for 'Sciampagnino Villa', featuring a funny character in a strange white suit, a huge red umbrella,

pockets and a basket overflowing with bottles which, together with the orange and yellow lettering, stand out prominently against the black background. Giorgio Muggiani, graphic designer, advertiser, caricaturist, sports manager and football referee, introduced an important innovation in graphic composition in his 1923 poster for Olio Diana: the product can, and the handle of the pan protrude from the white border that frames the poster, giving the impression that the scene depicted continues beyond the physical limits of the poster.



Fig. 21 - MAGA, Cordial Campari, 1921.

Fig. 22 - A.L. Mauzan, Anisetto Alberti, 1921.



Fig. 23 - Sego, Sciampa-gnino Villa, 1920.

Fig. 24 - G. Muggiani, Olio Diana, 1923.

We cannot deny Giuseppe Cappadonia's remarkable sense of humour; in his 1920 poster for 'Touring Oil', against a dark starry sky, he depicts a flaming red car hurtling through space at full speed, about to hit a perplexed and pained yellow-moon. Mario Bazzi's humorous and sarcastic streak is evident in the 'Concentrato 5 Oxid' poster, where an almost immaterial

figure, formed by a white shirt, underpants and socks, wanders around the black background holding up a bottle of the product with green and yellow lettering ensures its visibility. Federico Seneca, Perugia's long-standing graphic designer, in his 1928 poster for 'Pastina glutinata Buitoni' (both brands were part of the same holding company), depicts a highly stylised nun of St. Vincent [10] bringing a plate of pasta and hot broth to the sick. Note the colours chosen for the lettering, yellow, red, and orange, which clearly reference egg yolk. Finally, Leonetto Cappiello's 1929 poster for 'Nitrolian' features a black background cut diagonally by a ladder that a painter paints red while a woman descends the steps without leaving any marks on the freshly painted treads. The slogan reads: 'dries as soon as it is painted'.



Fig. 25 - G. Cappadonia, Touring Oils, 1920.

Fig. 26 - M. Bazzi, 5 Oxid, 1922.



Fig. 27 - F. Seneca, Pastina Buitoni, 1928.

Fig. 28 - L. Cappiello, Nitrolian, 1929.

6. Conclusions

'The raw materials available to Cappiello to convey his idea are essentially colour and movement' (Cappiello,

1981, p. 17); this sentence is symptomatic of how the artist managed to innovate and radically change advertising posters worldwide through the use of a few basic elements, making the communicative language of commercial posters simple and effective. His innovation lies not only in the introduction of dark backgrounds but more generally in the use of a monochrome background, whether green, red, blue or brown; this renewal makes the main image more recognisable and iconic, which, combined with the use of complementary colours for the figures and lettering, creates contrast and emphasises the composition. Between 1903 and 1920, Cappiello produced numerous dark-coloured posters, spreading their use among contemporary poster artists for over a decade. A large group of European artists followed in his footsteps, adopting black backgrounds in commercial posters, demonstrating the validity and quality of the innovative and revolutionary ideas of the great Leonetto Cappiello.

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9. Short biography of the author(s)

Marcello Scalzo - Associate Professor (PhD) at the Department of Architecture of the University of Florence in the disciplines of Drawing, Surveying, Graphics, Advertising and Video. Director of the Mediarc Festival and of the Photo Video Lab of the Department of Architecture. He is a lecturer, visiting professor, and member of editorial and scientific committees at Italian and foreign universities.

Notes

[1] Hollis R. (2005), *Graphic Design*, Thames & Hudson, London, p. 11.

[2] Meggs P.B., Purvis. A.W., (2006), *History of Graphic Design*, Wiley & Sons, New Jersey, p. 195.

[3] Viénot J. (1946), L. Cappiello - sa vie et son Œuvre, Edition de Clermont, Paris: 'The two artists had the same admiration for each other. When they first met, Lautrec came to Cappiello and said bluntly: "We were like two dogs for each other, we had to meet."' p. 74.

[4] Posters produced using the lithographic technique varied in size but were standard: the most common were 70x100 cm, 100x140 cm and 140x200 cm, reaching approximately 200x300 cm. The master plates usually measured 80x110, so larger posters were obtained by placing individual sheets side by side. Smaller sizes were also produced, including 25x35 cm and 50x60 cm posters, as well as postcard formats.

[5] Bargiel-Harry R., *Esthétique de l'affiche chez Cappiello*, in AA.VV. (1981), *Cappiello 1875-1942*, Ed. Réunion M.N., Paris, p.16.

[6] On the relationship between Cappiello and the printer Vercasson, see: AA.VV. 1981, pp. 113 ff., and Scalzo 2022b. pp. 124-125.

[7] Maurin Quina is an 'aperitif', a white wine flavoured with wild cherries, quinine, bitter almonds and cherries. 'Il Diavolo Verde' (The Green Devil) in particular evokes the 'fée verte' (the green fairy), the nickname given to absinthe, a cheap and highly alcoholic drink that was very popular during the Belle Époque.

[8] Cappiello produced a vast number of commercial posters with a black background; for the sake of brevity, we have limited ourselves to describing just a few examples from the first decade of the 20th century.

[9] On this story, see: Forni D., Forni R., (2008), *Sepo - settant'anni con l'arte*, Pendragon, Bologna, p. 79.

[10] The Daughters of Charity of St. Vincent de Paul were dedicated to caring for orphans and assisting the sick in hospitals.

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Chromatic Imperfection: Reimagining Colour as a Catalyst for Sustainable Fashion Design

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ABSTRACT

In the contemporary fashion world, where synthetic and standardised colours dominate, embracing colour imperfection challenges conventional notions of quality, desirability, and value. Accordingly, this paper explores the strategic role of visible colour imperfection in advancing sustainable practices within contemporary fashion design. Moving beyond chromatic ideals rooted in consistency, reproducibility, and standardisation, it interrogates how intentional colour irregularities can operate as expressive, ethical, and ecologically attuned design strategies. Situating colour as a medium of communication, material storytelling, and aesthetic value—rather than a purely decorative or technical attribute—the research draws from historical, cultural, and industrial perspectives to critique the dominance of mass produced, synthetic colour systems. It foregrounds the environmental impact of conventional dyeing practices while proposing alternative models that reframe chromatic variation as a meaningful aesthetic and ethical choice. The concept of the “aesthetics of imperfection” is employed to valorise irregularity as a quality that enhances product authenticity, sensory depth, and emotional resonance. Particular attention is given to recycled and repurposed colours, whose unpredictable and non-uniform qualities reflect material histories and embody principles of circularity. Through case studies and theoretical analysis, the paper identifies four design strategies that mobilise colour imperfection to communicate sustainability: expressive manual dyeing, mismatched combinations, natural ageing effects, and digitally or mechanically induced randomness. These approaches challenge consumer expectations, extend product lifecycles, and embed sustainability into fashion’s visual and material language. Ultimately, the study repositions colour imperfection not as a flaw, but as a vital dimension of ethical and resilient design innovation.

KEYWORDS: (Colour Design, Colour Imperfection, Sustainable Fashion, Imperfection Aesthetics, Design for Sustainability)

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1. Introduction

A contemporary perspective on design recognises colour as a multifaceted and influential element that extends well beyond mere visual appeal. It operates as a powerful tool capable of shaping perception, facilitating communication, and influencing both consumer identity and commercial viability. Colour communicates individual values, attitudes, personality traits, and orientations toward the environment, rendering it central to the emotional and psychological impact of design (Sullivan et al., 2017). Colour specialists understand the nuances of colour perception—how hues are experienced, why they may shift under varying conditions, and the diverse meanings they can embody. This expertise allows for the strategic deployment of colour to enhance both the desirability and marketability of products. Consequently, colour often plays a decisive role in determining a product's reception and commercial success (Holtzschue, 2017). The communicative power of surface and material colour is particularly striking: it can convey the essence of a design before its form is fully perceived (Kopacz, 2012). This pre-verbal, almost instinctive recognition underscores the potency of colour as a fundamental element of design.

Within fashion design, colour holds significant relevance across aesthetic, economic, and manufacturing domains. For example, colour forecasting is a core component of the collaborative practice known as fashion or trend prediction. This process involves anticipating the colours, fabrics, and styles that will resonate with consumers approximately two years in advance (Diane & Cassidy, 2005). Colour is among the first considerations in the development of seasonal collections and remains central to shaping aesthetic direction and engaging consumers (Jackson, 2007). It is also one of the most decisive factors in consumer purchasing decisions. In the context of garment manufacturing, effective colour management is essential to mitigate production issues and prevent the unnecessary consumption of natural and material resources. Challenges such as multiple dyeing processes, poor colour selection, rejection of flawed applications, production delays, increased costs, and elevated stress levels can all stem from inadequate colour control (Best, 2012). Thus, in fashion, colour is not merely a stylistic choice but a strategic and intrinsic component that communicates, evokes emotion, drives sales, and increasingly, intersects with sustainability concerns.

In parallel, colour also plays a pivotal role in advancing sustainable design practices (de Medeiros et al., 2025; Premier & Gasparini, 2014). Imagining a sustainable design future necessitates a critical evaluation of how colour is applied—promoting reflection and concrete actions such as reusing, recycling, and recovering colours

(Otiepková, 2021). Sustainable colour design must confront the environmental implications of the technological processes involved in colour production and reproduction (Perryman & Conway, 2021). This requires reimagining the role of the colour designer not just as a creative professional, but as a systems thinker (Calvo Ivanovic, 2025). Within this expanded framework, designers make strategic decisions that embed colour application and management within broader sustainability initiatives, ensuring alignment with environmental and ethical goals.

In the context of contemporary design and fashion, the pursuit of sustainability has emerged as a critical challenge, increasingly shaped by consumer perception and expectations. As ecological awareness rises, so does scrutiny over the environmental and ethical implications of production processes, including those related to colouration (Palumbo, 2023; Pansera & Owen, 2018). Colour, a seemingly aesthetic detail, is deeply entangled with industrial systems, cultural narratives, and economic imperatives. Synthetic and standardised colours dominate the visual landscape of modern consumer goods, reflecting a broader historical trajectory in which efficiency, reproducibility, and market consistency have become paramount (Casciani & Chen, 2023).

The prevalence of synthetic colours in industrial design and fashion is not incidental. Rooted in 19th-century innovations in chemical dyeing, the widespread adoption of synthetic pigments was driven by their cost-efficiency, durability, and chromatic intensity (Gage, 1999). These attributes aligned with the logic of mass production, enabling brands to maintain visual uniformity and recognisable identities across global markets (Donato, 2025). The Pantone Matching System, among others, epitomizes the industrial ambition to control and codify colour perception, ensuring predictability in production and branding (Neumann et al., 2023). Culturally, standardised colours reinforce aesthetic norms and consumer familiarity, contributing to perceived product reliability and brand trust. Economically, they reduce variability in manufacturing and facilitate transnational supply chains by offering a shared chromatic language (Palumbo, 2023).

However, this rationalisation of colour also marginalises local dyeing traditions and natural palettes, often associated with artisanal, slower, and more sustainable modes of production (Donato, 2025). Despite their industrial appeal, synthetic colours are increasingly scrutinized for their environmental impacts, particularly in water pollution and chemical toxicity (Pansera & Owen, 2018). In response, designers and scholars are exploring alternatives rooted in bioregional colour practices, plant-based dyes, and regenerative design principles. Yet,

shifting consumer perceptions away from synthetic colour aesthetics toward more ecologically attuned sensibilities remains a significant barrier (Neumann et al., 2023). Ultimately, the hegemony of synthetic and standardized colour in design and fashion exemplifies the tension between industrial efficiency and ecological integrity. Understanding the socio-technical systems underpinning this dominance is crucial to reimagining more sustainable chromatic futures that are both culturally meaningful and environmentally responsible.

2. The Research Background and Context

2.1. Beyond Perfection: Reframing Beauty Through the Aesthetics of Imperfection

The concept of the aesthetics of imperfection refers to the appreciation of aesthetic value in objects or experiences that diverge from traditional ideals of perfection. Throughout the history of aesthetic thought, debates have persisted regarding whether perfection constitutes a fundamental condition for beauty (Saito, 2017). This perspective challenges that assumption by attributing value to the incomplete, the flawed, and the non-standardised (Calvo Ivanovic, 2025). In this context, imperfection is not regarded as a deficiency, but rather as a meaningful and expressive quality. It often emerges through irregularity, disorder, complexity, and rough or textured surfaces (Saito, 2017). Marks of wear, damage, or signs of ageing—whether the result of natural processes or accidental occurrences during creation—are similarly embraced. Materials such as wood or leather, which acquire a patina over time, are particularly valued for their ability to record traces of use (Rognoli, 2015). Within sustainable design, this sensibility extends to visible recycled colour—stains, inclusions, or fragments of waste material—which function as visual records of a product's environmental history (Calvo Ivanovic, 2025).

Historically and culturally, the aesthetic of imperfection has deep and varied roots. In 18th-century Britain, the notion of the picturesque celebrated aesthetic irregularities such as architectural ruins, overgrown gardens, and textured or weathered surfaces (Saito, 2017). Similarly, the Japanese concept of *wabi-sabi*, which emerged in the 16th century through the practice of the tea ceremony, embraced irregularity, asymmetry, and surface flaws as signs of authenticity and transience. In this tradition, imperfections were sometimes even introduced intentionally, reinforcing the idea that imperfection could be an aesthetic principle (Salvia et al., 2010).

The attraction to imperfection unfolds across several dimensions. First, there is a dimension of sensory enrichment, in which irregular forms and complex textures expand the range of sensorial qualities that may be

appreciated, producing richer and more layered visual, tactile, or material experiences (Saito, 2017; Leone, 2018). Second, imperfection can serve to stimulate the imagination by prompting reflections on an object's original condition, the processes that shaped its transformation, or the impermanence of material existence (Saito, 2017). Third, a close relationship can be drawn between imperfection and authenticity. The traces of human touch, artisanal labour, and the passage of time contrast markedly with the polished uniformity of mass production, which is often perceived as sterile or depersonalised (Rognoli, 2015; Adamson, 2013). A fourth dimension involves the generation of aesthetic tension, arising from the contrast between pattern and anomaly—between regularity and the unexpected emergence of a crack, deformation, or singular feature (Leone, 2018). Appreciating such qualities requires a refined aesthetic sensibility, grounded in openness and a willingness to encounter objects on their own terms, without imposing idealised standards of perfection.

Beyond the aesthetic, this approach to imperfection carries significant ethical and environmental implications. It encourages the acceptance of transience and cultivates a more humble, less controlling relationship with the material world (Saito, 2017). Valuing imperfection aligns with sustainable practices by reducing the demand for flawless uniformity and encouraging the visible use of recycled, bio-based, or hybrid salvaged materials. The use of recycled pigments, for instance, not only reduces environmental impact but also allows the visual characteristics of a product to communicate its ecological values (Calvo Ivanovic, 2025). Nonetheless, this perspective is not without challenges. Cultural preferences for perfection continue to dominate, particularly in sectors where uniformity and precision—such as colour consistency and material performance—are non-negotiable. Shifting these expectations necessitates a deep cultural transformation. Moreover, the aesthetic of imperfection must be applied judiciously. The notion of a “negative aesthetic” reminds us of how certain imperfections—such as urban decay, broken infrastructure, or distressed clothing—can signify social neglect or systemic inequality. Taking aesthetic pleasure in such manifestations, risks overlooking or trivialising the underlying issues (Saito, 2017).

Ultimately, the aesthetics of imperfection offers a valuable framework for recognising the sensory richness, authenticity, complexity, and expressive tension inherent in what is not perfectly uniform, pristine, or flawless. It broadens the horizon of aesthetic experience while establishing links with ethical and ecological values. Properly understood, imperfection is not a flaw, but a site of meaning.

2.2. Rethinking Chromatic Perfection: The Dimensions of 'Good Colour'

To explore the concept of imperfection in relation to colour, it is first necessary to examine the parameters that define chromatic perfection—typically associated with the notion of 'good colour quality' in product design and manufacturing, including fashion. These parameters encompass a complex interplay of historical, technical, commercial, and sustainability-related factors. The idea of 'good colour' is relatively modern, emerging in the eighteenth century alongside the development of synthetic pigments, colourants, and dyes, and with them, an increasing ability to control the colouring process with precision. Before this period, colour production relied exclusively on bio-based materials. As Anita Quye notes, one of the earliest known uses of natural dye—estimated to be around 6,200 years old—is a piece of woven cotton dyed blue with the *Indigofera* plant. She further argues that the ancient practice of dyeing textiles has profoundly influenced the evolution of fashion (Atkinson, 2022).

Although natural colouring methods were foundational to early textile production, they presented several limitations when assessed against today's quality benchmarks—particularly in terms of colour fastness, such as resistance to light, washing, perspiration, and abrasion. Nevertheless, these limitations were not perceived at the time as shortcomings; rather, they were seen as inherent characteristics of each colouring technique. The rise of global trade in the sixteenth and seventeenth centuries expanded access to diverse dye sources, making vibrantly coloured textiles more widely available. However, as Quye observes, the distinction between social classes was maintained through the quality of materials and the longevity of colours: "The difference between wealthy and poor would have been in the craftsmanship – how long the colours lasted and the quality of the material" (ibid). Dyeing was a highly skilled practice, involving the use of mordants—additives that enhanced the vibrancy and fixability of dyes on fabric.

The discovery of synthetic aniline dyes by William Perkin in 1856 marked a turning point in colour production. These synthetic alternatives enabled mass production of coloured textiles, offering consistent colour between batches and simplifying integration into industrial processes. By the nineteenth century, 'good colour' had become defined by three core attributes: it had to be aesthetically appealing, durable, and suitable for application with ease and efficacy (Lowengard, 2006). Although economic considerations such as cost and perceived value often influenced these standards, the foundational criteria—beauty, permanence, and fitness for purpose—have remained largely consistent over time.

From a technical and manufacturing standpoint, colour management is now a fundamental component in ensuring colour quality and achieving chromatic perfection (Best, 2012). This process typically begins with the creation of precise colour standards, which serve as benchmarks against which reproduced colours are evaluated (Calvo Ivanovic, 2022). The closer a reproduction comes to matching the original standard, the higher the perceived quality of the dyeing process. In addition, good colour must exhibit consistency across varied lighting conditions, from natural daylight to artificial store or home lighting. Such colour constancy is essential for maintaining uniform visual outcomes across different fabric types and qualities. Equally critical is a colour's performance in terms of fastness. A high-quality colour must resist fading from sunlight, washing, or general wear, and must not transfer onto other garments (Best, 2012). Evaluation of these qualities involves both expert visual assessments—conducted under standardised conditions—and instrumental testing using colourimeters and spectrophotometers. These instruments generate numerical values that correspond to colour perception, allowing quantifiable comparisons between a colour sample and its standard (Best, 2012; Calvo Ivanovic, 2022). A colour is generally regarded as high-quality when the differences between the standard and the sample are either imperceptible to the human eye or fall within acceptable tolerances (Calvo Ivanovic, 2025).

From a commercial standpoint, consumer perceptions of 'good colour' are closely aligned with prevailing fashion trends, but also encompass enduring classics such as black, navy, and taupe. Consumers expect a wide range of aesthetically pleasing colours that also meet performance demands across various use cases. Moreover, the perceived quality of colour contributes directly to a product's overall value, particularly concerning price expectations. In this sense, colour perfection in fashion and product manufacturing is defined by visual appeal—whether trendy or timeless—as well as by technical reproducibility, consistency, and durability.

This paper aims to critically examine and challenge prevailing assumptions about 'good colour' and chromatic perfection by introducing environmental concerns into the discourse. As the colour industries become increasingly responsive to ecological and ethical imperatives, notions of quality and perfection may shift. While traditional fastness remains important, sustainable approaches—such as designing colour to fade appropriately within a product's lifecycle—may redefine what constitutes a high-quality colour. Ultimately, a contemporary understanding of good colour must integrate aesthetic, functional, ethical, and environmental values into a cohesive and responsible framework.

2.3. The Semiotics of Visible Recycled Colour

In contemporary fashion discourse, colour is not only a visual or aesthetic element but a communicative medium capable of narrating values, identities, and ecological awareness. Within this framework, recycled colours—those derived from post-consumer or post-industrial waste or reclaimed through material recovery processes—are gaining attention for their storytelling potential in sustainability-focused fashion design (Siamwalla, 2021). As the fashion industry seeks to mitigate its environmental impact, recycled colours offer both symbolic and material responses to the imperative of circularity. Unlike synthetic standardised hues, recycled colours emerge from unpredictable chromatic sources, including dyed textile scraps, industrial residues, or organically pigmented waste streams (Lara et al., 2022). Their variability, far from being a limitation, is intrinsic to their narrative capacity. These colours embody the history of previous material lives and production systems, conveying a story of transformation, waste revalorisation, and resistance to homogenised aesthetics (Furferi et al., 2022). They foster a deeper connection with consumers who seek authenticity, transparency, and emotional engagement with the products they wear (Gilmore & Pine, 2007). Recycled colours also contribute to the semiotics of sustainability in fashion branding. Their often-muted, earthy, or uneven tonalities visually communicate an alignment with natural processes and resource-conscious manufacturing (de Medeiros et al., 2025). As such, they become visual markers of ethical commitment and environmental values—particularly appealing to the growing segment of consumers who align their purchases with sustainability-driven lifestyles (Glasper et al., 2024). The uniqueness of each recycled batch challenges the paradigm of mass production by celebrating imperfection and temporal variation, reinforcing narratives of uniqueness and craftsmanship. From a systems perspective, recycled colours function as both a material and a symbolic node in the transition to circular fashion. They support upcycling initiatives and reduce the need for virgin dye substances, thus decreasing water use and chemical discharge (Bianco et al., 2022; Harmsen et al., 2021). Moreover, their incorporation into design practices invites new forms of co-creation between designers, suppliers, and recyclers, expanding the role of storytelling beyond marketing and into the realm of supply chain innovation and transparency (Niinimäki & Karell, 2019). In sum, recycled colours offer a multisensory storytelling medium in sustainable fashion—embodying the histories of materials, the ethics of production, and the aesthetics of ecological care.

2.4. Research objectives and relevance to sustainable practices

According to the aforementioned context, this paper investigates the role of visible colour imperfection as a design strategy that aligns aesthetic innovation with sustainable development in the fashion industry. By challenging dominant norms of colour standardisation, it explores how intentional irregularity and chromatic unpredictability can enhance material storytelling, extend product lifecycles, and redefine consumer perceptions of quality and value. The research is situated within the broader discourse on circular design, proposing that embracing colour variation not only reduces environmental impacts—by avoiding intensive dyeing processes and valorising recycled materials—but also fosters more authentic, emotionally resonant connections between products and users. The structure of the paper follows a progressive exploration, beginning with a theoretical overview of colour and imperfection in fashion, followed by an in-depth analysis of selected design strategies and case studies that integrate visible colour irregularity. Each section reflects on the cultural, material, and perceptual implications of these practices. Ultimately, this paper argues that moving beyond uniformity in colour use offers an opportunity to reimagine sustainability as a visible, expressive, and desirable dimension of contemporary fashion.

3. Methodology

The research adopted a qualitative methodology, primarily conducted through desk research, literature review, and case study analysis.

The first phase involved a scoping literature review to provide a preliminary assessment of the scope and scale of existing research. This review aimed to identify the nature and extent of available evidence, including ongoing studies and emerging research (Grant and Booth, 2009). The literature search spanned both academic and non-academic sources, using keywords such as “imperfection,” “aesthetics of imperfection,” “colour sustainability,” “sustainable colour,” “ethical colour,” “circular colour,” “sustainable fashion design,” and “circular fashion,” among others. Sources included academic journals (indexed and non-indexed), conference proceedings, books, sustainability reports, blogs, and other relevant publications across the fields of colour, design, sustainability, and fashion. Through a systematic screening process, the initial pool of 56 sources was refined to 22 relevant studies. The results of this phase are presented in the Main Findings section.

Building on the literature review findings, the second phase of the research involved a case study analysis. As defined by Teegavarapu and Summers (2008), this is a

systematic and empirical approach used to examine contemporary phenomena within their real-world context—particularly when the boundaries between the phenomenon and its context are not clearly defined. Drawing from both the fashion design practices identified in the literature review and the authors' expertise—particularly in colour design and fashion design for sustainability—a final selection of twenty case studies was made. These include fashion brands, designers, collaborations, and projects from Africa, Asia, Europe, Oceania, and America. These were chosen according to specific inclusion criteria designed to ensure relevance to the core themes of colour imperfection and sustainability in fashion design (see Table 1).

The first criterion was (i) the intentional use of colour imperfection as a design strategy. Only cases in which designers deliberately employed imperfect or non-uniform colours for aesthetic purposes were included. Instances where colour irregularities resulted from production errors or poor-quality processes were excluded. This ensured that colour imperfection was considered a purposeful and meaningful design tool. The second criterion was (ii) a demonstrated commitment to sustainability and circular design. Each case had to reflect environmental responsibility, such as the use of recycled materials, upcycling, natural dyes, low-impact processes, or waste-reduction strategies. This alignment with circular design principles was essential to the research framework. A third criterion was (iii) transparency regarding process and material origins. Selected cases needed to clearly communicate the sources of their materials and the processes used to achieve colour variation. This could be through documentation, storytelling, or other forms of public-facing communication. Transparency not only underscores ethical design practices but also educates consumers about the environmental and social impacts of material choices. The fourth criterion was (iv) the use of innovative or experimental colour techniques. Case studies had to explore unconventional colour aesthetics—through unexpected pairings, unpredictable results, or materials that naturally yield imperfect hues. This helped ensure that innovation in colour design was a key feature of the selected examples. Finally, (v) recognition or impact within the field was considered. Cases were selected based on their contribution to the discourse of sustainable fashion—whether through exhibitions, publications, awards, or citations in the broader sustainability community.

The selected case studies were then categorised into four design-driven approaches that illustrate how colour imperfection is integrated into contemporary fashion design:

Material-led design, which emphasises the innovative use of recycled colour through material experimentation, such as repurposing textile waste or post-consumer fibres;

Pattern and texture strategies, where colour irregularities are employed to create distinctive patterns, gradients, and textures that convey sustainability narratives;

Modular and adaptive colour design, which explores how modular garment construction enables flexible colour combinations based on material availability, supporting both assembly and disassembly;

Colour unpredictability and spontaneity, where designers embrace variation and irregularity, rejecting uniformity in favour of dynamic and expressive outcomes.

These approaches provide a framework for understanding how designers engage with colour imperfection—not only as a creative tool but also to challenge traditional aesthetics, enhance sustainability narratives, and shift consumer perceptions. Through these design approaches, the case studies illustrate how colour imperfection can redefine material aesthetics and support a more sustainable, circular fashion system. Then, the analysis of case studies included 'within-case observation', identifying key sustainable approaches, colour techniques and imperfection patterns, and sustainable fashion design insights within each case. After that, a 'cross-case observation' was conducted, looking for common themes, variations, contradictions, and comparing how themes and patterns appeared across cases.

Case Study	Location	Description / Relevance	Reference
Faber Futures - Assemblage 002	United Kingdom	Faber Futures is a biodesign lab fusing design thinking with living biological systems to generate scalable models for sustainable textile dyes	Link to Faber Futures
BioChromatic - A biannual capsule collection with biogenic dyes	Germany	This project by Loreto Binvignat and Vienna Textile Lab was born out of the impending need to reverse the textile dyeing industry's biggest problem: the water waste and pollution problem	BioChromatic Project
Kaliko Collective	Germany	Kaliko is a natural-dye studio based in Berlin. Founded in 2016 by Ania Grzeszek, with the mission to spread love for natural textiles and educate about healthy processes of making cloth	Link to Kaliko Collective
Make Fashion Clean (MFC), Tie-Dye Inc.	Ghana	MFC is a non-profit organisation whose mission is to reduce global fashion pollution by upcycling denim and tie-dye products out of textile waste sent to Ghana from the Global North, and educating about pollution	Link to Make Fashion Clean
Shibori Australia	Australia	With a focus on colour, texture, and innovation, Shibori has garnered acclaim for its art-based sustainable textiles and fabric manipulation, maximising the use of dyes and minimising waste	Link to Shibori Australia
Yohji Yamamoto	Japan	His philosophy of longevity, quality, anti-consumerism, and respect for imperfection offers a deeply rooted, holistic approach to sustainability, one that critiques the fashion system itself	Link to Yohji Yamamoto
Fili Pari	Italy	Fili Pari is an Italian textile-tech startup that transforms unconventional raw materials, like marble powder, into innovative, sustainable fabrics. The brand combines creativity with scientific research to offer vegan, water-resistant garments with a strong focus on circular economy and local craftsmanship	Link to Fili Pari
Tu Lizè	Italy	Tulizè embraces sustainability through local Italian production, upcycling surplus military uniforms, and valuing slow fashion with handcrafted crochet and embroidery, merging eco-conscious choices with artisanal luxury	Link to Tu Lizè
Romance was Born - Forever	Australia	The RWB Forever project is leaning into the collection and reuse of vintage fabrics, using a treasure trove of fashion remnants while closing the loop on waste	Link to Romance Was Born
Desigual x Ecoalf	Spain	This collaboration embraces sustainability by upcycling existing garments using recycled materials, reworking designs with new colours and denim elements, and creating a limited 500-piece collection that reduces waste and promotes reuse	Link to Desigual x Ecoalf
Rei Kawakubo	Japan	Her radical approach to fashion critiques the systems that make the industry unsustainable in the first place. Her designs promote longevity, creativity, and thoughtful consumption—all fundamental to a sustainable future in fashion	Link to Rei Kawakubo
BODE	United States	BODE embraces sustainability by repurposing vintage textiles, prioritising material traceability, reducing waste, and crafting one-of-a-kind garments that honour cultural history and resist fast-fashion's mass produced model	Link to BODE
Verabuccia	Italy	Verabuccia's materials transform discarded pineapple peels into innovative, 100% plant-based textiles through a patented, plastic-free process, promoting the circular economy and reducing agricultural waste	Link to Verabuccia
Benét Mattias	United Kingdom	Benét uses recycled and dead-stock yarns, embracing imperfections, and crafting bold, ethical knitwear that challenges norms, celebrates individuality, and minimises environmental impact through conscious design	Link to Benét Matthias

WRÅD, Graphi-Tee Project	Italy, United Kingdom, Denmark	WRÅD promotes sustainability by using recycled materials like graphite powder, reducing harmful chemical use. It drives awareness, innovation, and action, merging fashion with environmental and social responsibility	Link to WRÅD
Lebiu	Italy	Lebiu upcycled cork waste into bio-based, cruelty-free materials. Their process reduces CO ₂ emissions, supports local communities, and preserves Sardinian cultural heritage	Link to Lebiu
Greg Lauren	United States	Greg Lauren champions sustainability by upcycling vintage military fabrics and scraps into unique garments. His "GL Scraps" initiative ensures no material is wasted, blending artisanal craftsmanship with eco-conscious design	Link to Greg Lauren
Polybion x Ganni Lab - Celium	Mexico, Spain	Polybion and GANNI's collaboration introduces Celium™, a bacterial cellulose material derived from fruit waste. This innovative, plastic-free leather alternative is carbon-negative, biodegradable, and showcases a sustainable future for fashion	Link to Polybion
Eva Sonneveld - Green Whisper Project	The Netherlands	This project transforms banana agricultural waste into biodegradable textiles, reducing environmental impact, supporting local economies, and minimising resource consumption	Link to Eva Sonneveld
Boro Boro	United States	Boro Boro revives vintage kimono and traditional mending practices, reducing waste, preserving endangered Japanese textile arts, and encouraging mindful, inclusive fashion rooted in cultural heritage and craftsmanship	Link to Boro Boro

Table 1. The twenty selected fashion design case studies and their relevance to the research.

4. Main findings

Phase one of the research, the literature review, revealed the following key insights:

- A significant lack of specific, peer-reviewed academic literature defining the concepts of “colour perfection” and “colour imperfection”, concerning design or related fields.
- A notable scarcity of studies exploring the role of colour as a catalyst for ethical and sustainable practices in design broadly, and fashion design.
- An emerging body of work discussing “imperfection” and the “aesthetics of imperfection” concerning contemporary design and fashion practices.
- A collection of ongoing, yet largely unconnected, design and fashion practices and cases —often individual or collective efforts—aimed at adopting more ethical and sustainable approaches to colour use across various stages of the design and manufacturing process.

The outcomes of phase one highlight a critical gap in current academic and design discourse around colour, particularly in the context of sustainability and ethics. This reveals a conceptual blind spot. This lack of terminology not only limits theoretical development but also meaningful dialogue around how colour functions within value systems of contemporary design practice. Furthermore, the scarcity of research examining colour as a tool—or even a site—for ethical and sustainable transformation

underscores a missed opportunity within design. While material choices and production methods have received significant attention in sustainability discourses, colour remains largely under-explored as an agent of change. This indicates a pressing need to reposition colour not merely as an aesthetic outcome, but as a strategic and ethical design element.

On the other hand, the emerging body of work around “imperfection” and the “aesthetics of imperfection” suggests growing critical interest in counter-narratives to perfectionism in design. However, this discourse remains largely fragmented and rarely intersects with colour-specific concerns. This fragmentation is mirrored in practice: while there are many innovative and inspiring examples of designers and collectives embracing more sustainable and ethical approaches to colour, these efforts are often isolated, lacking the cohesion or visibility that would support broader cultural or systemic shifts.

Building from these findings, the case study analysis described above resulted in the definition of four key strategies for using colour imperfection as a visual driver for communicating sustainable fashion design practices and decisions.

4.1. Strategy 1: Uneven, expressionist, or irregular colour applications

Essence: Human-made irregularity through traditional and innovative colour techniques.

This strategy centres on hand-made processes and techniques, often emerging from the recovery, reuse, and

upcycling of textiles, fabrics, and garments through manual re-colouring. It also embraces the unpredictable experimentation with both traditional and innovative natural dyeing methods—approaches that preserve not only material and immaterial heritage but also local knowledge and practices. The resulting surfaces are marked by uneven and unexpected outcomes. Visually, this strategy is defined by colour irregularities: hand-painted aesthetics, expressive brushwork, subtle shifts in hue from manual application, and uncontrolled colour transitions. Organic spreads and spontaneous patterns emerge from techniques that inherently embrace randomness—such as tie-dye, dip-dye, shibori, and batik. Colour variations also result from hand-mixed pigments rather than precise mechanical systems, along with accidental splashes or freehand strokes. At its core, this approach celebrates imperfection, highlighting the artisanal, tactile, and organic qualities of colour (see Fig. 01).

We find this strategy mainly in the following cases: Faber Futures - Assemblage 002, BioChromatic, Kaliko Collective, Make Fashion Clean (MFC), Shibori Australia, Yohji Yamamoto.

4.2. Strategy 2: Asymmetric, mismatched, unconventional pairings.

Essence: Colour chaos through unexpected combinations and imbalance.

This strategy embraces unconventional colour combinations and juxtapositions, deliberately moving away from hegemonic theories of colour harmony and traditional selection methods. It emerges from practices of recovering, reusing, repairing, and repurposing cloth and garments—often through patchwork, asymmetry, collage, and mix-and-match techniques. The approach favours unorthodox, clashing, or instinctive colour choices over carefully curated palettes. Visually, it results in unexpected contrasts and unbalanced compositions—where one area may be intensely saturated while another remains muted—evoking a raw, improvised aesthetic. Disharmonic pairings, such as bright neon set against earthy tones, or deliberately mismatched fabrics and textures, challenge conventional notions of taste and cohesion. Visible construction and repair are key elements as well, with contrasting threads or fabric patches intentionally highlighting flaws—reminiscent of Kintsugi, but for fashion. The outcome is often seen in upcycled garments, streetwear, or expressive, experimental fashion that resists polish in favour of individuality and disruption (see Fig. 02).

We find this strategy mainly in the following cases: Fili Pari, Tu Lizè, Kaliko Collective, Romance was Born - Forever, Desigual x Ecoalf, Rei Kawakubo, BODE.

4.3. Strategy 3: Natural and weathered colour effects

Essence: Timeworn, faded, or naturally distressed colour changes.

This strategy stems from embracing the natural shifts in colour that occur over time—changes brought on by lifespan, wear, and exposure. It celebrates the aesthetics of colour imperfection and relativity, where garments and fabrics show visible signs of ageing: sun-faded surfaces, attrition marks, and colour loss from repeated washing. These garments carry the traces of their past, revealing layers of colour, patina, stains, and discolouration. Textiles may appear rust-dyed, distressed, or show uneven dye absorption, all of which contribute to a sense of depth and character. Bleached effects, gradients, and fading introduce unexpected transitions and organic patterns, often shaped by weather and environmental conditions. The result is a palette of naturally softened tones that evoke a lived-in, timeworn look (see Fig. 03).

We find this strategy mainly in the following cases: Verabuccia, Benét Matthias, WRÅD, Graphi-Tee Project, Lebiu, Greg Lauren.

4.4. Strategy 4: Unpredictability and Spontaneity: Rejecting Uniformity

Essence: Colour randomness and imperfection due to mechanical, digital, or disruptive technological effects.

This strategy arises from a spirit of experimentation with innovative sustainable materials and colouration technologies, embracing process over perfection. Bio-based, composed, waste-fibres often offer heterogeneous and textured surfaces, where visible recycled colour inlays can be perceived. The outcome is characterised by visual noise, textural and grainy finishes, colour distortion, and material or surface inconsistencies, offering a stark contrast to flat, clean, or smooth colour applications. Irregular colour effects also emerge through digital imperfections such as pixelation, colour shifts, glitches, and printing misalignments. Techniques like block printing, screen printing, and stamping introduce additional irregularities, including accidental colour bleeds and ink variations, which disrupt otherwise seamless gradients and perfect hues. At its core, this approach reclaims value in the imperfect—garments and fabrics that might otherwise be discarded as flawed, erroneous, or waste. Instead, it frames spontaneity, surprise, and disruption as central design values (see Fig. 04).

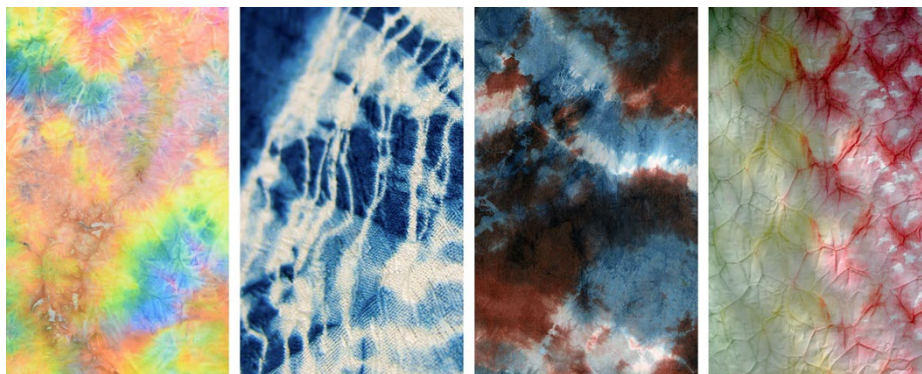


Fig. 01: Examples of Colour Imperfection according to Strategy 1. From left to right, photos by Stephen Ally, Naukhel, Yuha Park, and Teona Swift, respectively.



Fig. 02: Examples of Colour Imperfection according to Strategy 2. From left to right, photos by Shimo Yann, Erik Alfaro, Alpha Paul, and Engin Akyurt, respectively.



Fig. 03: Examples of Colour Imperfection according to Strategy 3. From left to right, photos by Clay Leconey, Enging Akyurt, Second Breakfast, and Creative Morghan, respectively.

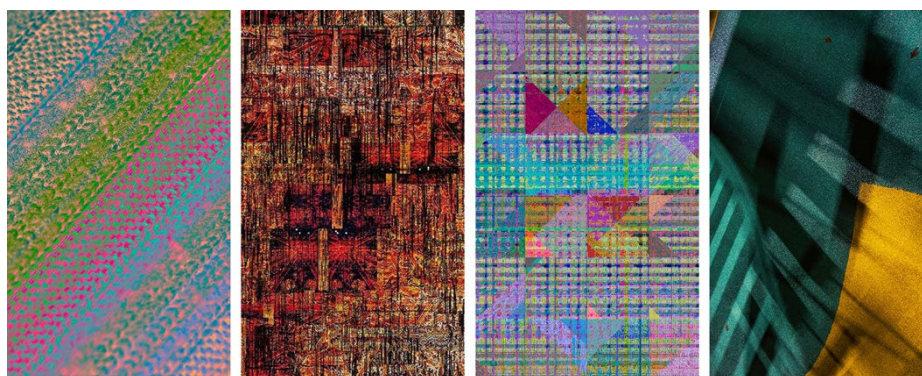


Fig. 04: Examples of Colour Imperfection according to Strategy 4. From left to right, photos by Daniela Paola Alchapar, J. Bushnell, Ignotus, and Marjan Blan, respectively.

We find this strategy mainly in the following cases: Polybion x Ganni Lab - Celium, Eva Sonneveld - Green Whisper Project, Boro Boro.

5. Conclusion

This research has critically examined the role of visible colour imperfection as a deliberate and meaningful strategy in contemporary sustainable fashion design.

By challenging dominant paradigms of chromatic uniformity and industrial perfection, the study reframes colour irregularity not as a flaw, but as a potent design methodology operating at the intersection of aesthetic disruption, ethical engagement, and ecological sensitivity. In doing so, it addresses a critical gap in design discourse: the limited recognition of colour as a transformative agent in advancing sustainable practices.

The study demonstrates that embracing colour imperfection can provoke a substantial shift in aesthetic values. It challenges deeply embedded associations between perfection and desirability, proposing instead a more expansive and inclusive visual language that recognises irregularity, variability, and unpredictability as sites of creative and ethical potential. Through the lens of the “aesthetics of imperfection,” chromatic inconsistencies—be they the result of manual dyeing, mismatched compositions, ageing processes, or experimental techniques—become visible expressions of process, provenance, and temporality. These aesthetic strategies not only contest normative standards of acceptability in fashion but also suggest new pathways for visual pleasure, emotional connection, and authenticity in design.

This reframing has important implications for sustainable fashion practices. The four strategic approaches identified—material-led design, pattern and texture variation, modular chromaticity, and spontaneous imperfection—demonstrate how colour can communicate values of transparency, circularity, and ecological responsibility. When designers embrace colour variation as a material narrative, they extend the lifecycle of garments, valorise waste materials, and resist homogenised production models. For the fashion industry, this implies a fundamental shift in how quality is defined and marketed, encouraging innovation in dyeing processes, supply chain transparency, and consumer education.

At a broader cultural level, the research reflects and contributes to an ongoing shift towards embracing imperfection as a value rather than a limitation. In positioning chromatic irregularity as both a visual strategy and an ethical proposition, it challenges prevailing assumptions about what is acceptable or desirable in

fashion. This cultural shift—while still emergent—holds transformative potential for design education, branding practices, and industry standards, fostering a more inclusive and materially engaged vision of sustainable fashion.

Further research is needed to explore consumer perceptions of colour imperfection in greater depth, particularly in relation to emotional durability, trust, and perceived value. Empirical studies could investigate how irregularity influences purchasing behaviour or post-consumer garment care. Additionally, there is scope for developing practical frameworks to support the integration of colour imperfection into scalable design and production systems. Collaborative approaches across disciplines—design, material science, cultural theory, and sustainability studies—will be essential in advancing this emerging field.

Ultimately, by repositioning colour imperfection as a site of aesthetic innovation and sustainability engagement, this study invites a reimagining of fashion practice—one that is materially honest, ecologically aware, and culturally attuned to the beauty of the imperfect.

6. Conflict of interest declaration

The authors declare that there is no conflict of interest regarding the publication of this paper.

7. Funding source declaration

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8. Short biography of the authors

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Marbled is the new green. Polymeric polychromy as a contemporary code of sustainability.

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ABSTRACT

The increasing environmental and symbolic criticism of plastic materials - once celebrated for their modernity and accessibility - highlights a growing disconnect between industrial material practices and contemporary sustainability values in design. There is a need to better understand how aesthetic choices such as polychromy intersect with ecological awareness, particularly in the use of synthetic materials in product, furniture, and interior design. The study builds upon design theory, material culture studies, and sustainability discourse. It situates plastics within a broader historical and socio-political context, examining their role in shaping mass production and aesthetic standards in the twentieth century. The framework also engages with current debates on decentralization, social innovation, and material ethics. The research aims to (1) analyze the evolving perception of plastics in relation to sustainability and aesthetics; (2) investigate the role of color (polychromy) in these perceptions; and (3) identify and map emerging practices that reflect a shift toward more ecologically and socially responsible design models. From a methodological point of view, the study employs quantitative and qualitative desk research, including literature review and case study analysis, to examine historical trends, current initiatives, and design practices related to the use and perception of plastics. Findings indicate that the traditional models of centralized, industrial plastic production and re-processing - once associated with progress and democratization (De Fusco, 2007) - are in crisis. Public perception has shifted due to increasing awareness of plastic pollution and its health and environmental impacts (Kießling *et al.*, 2017; Joseph *et al.*, 2016). This shift has spurred both grassroots and institutional responses, including bans, design innovations, and alternative production models. Polychromy, historically tied to synthetic materials, now plays a symbolic role in expressing ecological values, material reuse, and social engagement. The study concludes that a new chromo-material paradigm is emerging - characterized by ecological awareness, decentralized practices, and aesthetic reinterpretation of synthetic materials. This phenomenon is historically traceable, widely diffused, and indicative of broader systemic transformations in design. The research contributes to understanding how color and material choices are becoming critical tools in advancing sustainability and rethinking industrial production in design fields.

KEYWORDS Marbled plastic, Confetti texture, Aesthetics of sustainability, Open recycling, Circular economy, Diversified series

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1. Introduction to chromo-material inhomogeneities in design practices

Natural materials have, by their own nature, specific peculiarities, often assimilated to local characteristics, and non-uniformities of visual and tactile features: variations, textures, veins, capillarities. We can consider, for example, the different types of wood, plant fibres, stones, leathers, metals and their oxidation processes, soils and clays. Historically, even "artificial building materials", so the ones deriving from substantial transformation processes on natural materials, have always maintained chromatic characterisations that are specific, diversified and identifying from time to time. These granulometries, small defects and air bubbles can be seen as clear traces of their typicalities, and so of the links, with their territories, their techniques and their cultures of origin. Consider, for example, terracotta, cocciopesto, conglomerates, artisanal glasses, grits, Venetian terrazzo. Starting from the first applications in the 20th century, chemical-based polymers introduced, instead, the possibility of obtaining, without painting interventions, chromatically and tactilely uniform and stable shapes. For Renato De Fusco "it is possible to distinguish a first imitative phase (the historical plastics) from a phase of the material as a surrogate of others (the plastics of scarcity), up to the surprising developments of it due to technological advancement (the plastics of opulence)" (De Fusco, 1985). The material that most characterized the twentieth century, therefore, was initially used, for both commercial and even ecological purposes, as a replacement for more precious materials, or materials that were difficult to find, declared illegal or, simply, no longer ethically acceptable (materials such as ivory, animal bones and horns, coral, turtle shells, furs). In large-scale production processes, therefore, the standardization of "light recognizability" (Manzini, 1986), of "performance democracy" (Branzi, 2008) and of the monochromaticity of goods produced in plastic favors a new design paradigm that became a global phenomenon with the economic boom of the post-war period. The "promise" of polymers is to provide large social groups with cheap, light, available, homogeneous products, all "equally perfect". «In the 1950s and 1960s, the production of various new materials, especially plastics, represented, for many designers, the ideal tool for pursuing innovation and the well-being of society. These materials were attributed a strong symbolic and political value, aimed at expressing concepts and ideals, such as those of freedom, equality and democracy» (Cecchi, 2019). This post-Marxist ideal proposed, through plastic goods, a new model of universality that, however, tended to exclude the concepts of difference and localism and that, relying on a general optimism, failed to grasp the socio-environmental implications that, in a few decades, have generated global

crises that are evident today (Fig. 1). Gaetano Pesce was one of the first designers to radically criticize this propagandistic idealization of the homogeneity of polymeric materials and, more generally, the desire of companies, which were increasingly globalizing and addressing mass markets, to "reduce human needs to standards" (Martino, 2007). Pesce himself, who has been experimenting for years with less "dictatorial", rigid or "boring" possibilities of using plastics, rubbers, resins and foams, states: «it is with the ideology of functional-rationalism that the most sublime and hidden repression of the consumer has stabilized, bartering it with social motivations. [...] And our life has significantly lost spontaneity, replaced to the point of nausea by everything that prevents the free and individual self-determination of taste» (Pesce, in Baroni 1982). With Pesce, plastic becomes a diversified, empirical, spontaneous, heterogeneous, random material. It is conceived as open in its manipulative, aesthetic and expressive possibilities. Pesce then intuitively, well in advance, the possibility of imagining production processes of proximity and low complexity, typical of the technological equipment of current fablabs. "I believe that many of today's materials, if studied carefully, would allow us to bring the factory into the home just as information technology has allowed us to bring the office into the home. Some chemical processes can be brought into the home and some products no longer require specialised labourers and production places far from the users. Instead, without this detachment between object and consumer, it will be possible to give shape and color to the specific needs of each person" (Pesce, interview with C. Martino, April 2001, in Martino, 2007).

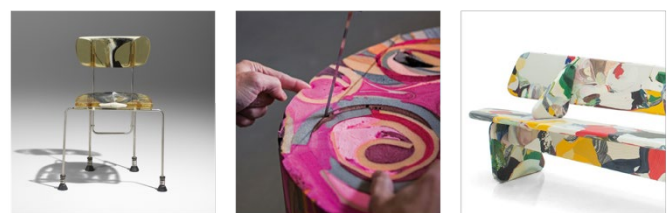


Fig. 1. Limited editions. From left to right: Gaetano Pesce (Italy) chair model "543 Broadway" 1993, Massimiliano Adamo (Italy) "Gommapiuma Décor" 2013, Dirk van der Kooij (The Netherlands) "Menhir bench" 2014. The three products included in this collection are made using three different processes and materials (resin, sponge, melted plastic). These are limited edition products, each with its own distinctive aesthetic, where the designers have intervened to maximize the aesthetic effect of variation and chromatic mixture.

2. Distributed models of polymeric recycling. The emergence of a new aesthetic of the sustainable

Gaetano Pesce's reflection can be interpreted as the premise for a phenomenology that is globally widespread today. In pre-industrial society, the design and production of artifacts took place within a specific and narrow local community and was based on its resources and knowledge (Vitta, 2001).

The last 150 years of industrial evolution, then, have been dominated by linear models of production and consumption, which involve in manufacturing goods from raw materials, sold, used and then discarded as waste, through centralized, specialized production models based on economies of scale and dislocated with respect to consumption centers. This model largely replaced a traditional economy that maintained high levels of reuse and regeneration but required more labor and yielded lower returns on investment (Maffei & Bianchini, 2015). It generated unsustainable levels of resource consumption and waste production. The contemporary economy currently seems stalled in a system in which everything, from the economics of production to contracts, and from regulation to people's behaviour, continues to uphold the linear model of production and consumption, but this system has shown its limits and is weakening with the rise of several trends: awareness of the exhaustibility of resources, stricter environmental regulations, digital technologies for tracking materials, and changing consumption patterns (more access-oriented than ownership-oriented). Those patterns are pushing towards alternative models based on the concept of circularity and the idea of organising human activities in distributed systems.



Fig. 2. Critical Design. From left to right: Johé Bruneau (France) "Énergie Fossile" - 2019, Shahar Livne (Israel) & Violetta Barba (Italy) "R.evolutionary matters" 2019, Studio Swine (UK). The aesthetics that emerge from plastic melting processes can also be found in artistic and critical design projects that aim to stimulate speculative contestations of the current production system.

The circular economy has thus emerged as a key topic of discussion in political and economic and academic

debates about industrial production, energy efficiency, and sustainable development (Moreno, Charnley *et al.*, 2016, 2018, 2021). It emerges as a paradigm capable of transforming the relationship between ecological systems and economic activities. Studies that have recently increasingly focused on this model have developed numerous tools and methodologies to support the transition to more sustainable production and consumption patterns (Rotondo, B., Bakker, C., Balkenende, R., & Arquilla, V., 2025).

Although we recognize that the circular economy benefits from interdisciplinary research, technical aspects dominate theoretical reflection. Authors like Ann Thorpe point out that circularity should be considered a social issue with a technical component, not the other way around (Thorpe, 2010). This contribution aims to explore the social significance of aesthetic changes related to sustainability by linking the polychromaticity of new plastic products charged with ecological principles to distributed systems and the concept of cosmopolitan localism.

Cosmopolitan localism, a term coined by Wolfgang Sachs of Germany, refers to a place-based way of life in which solutions to global problems are designed for local circumstances and adapted to specific social and ecological contexts, while being globally connected to exchange information, technologies and resources (Sachs 1999 in Manzini 2009, 2012, 2013). If we apply cosmopolitan localism to production systems and reverse chains, we find that it is similar to models based on the principle of distributed systems. This is a model that has a long-standing history in computer science and describes an environment in which the various components are distributed over several networked devices. More recently, this concept has also been explored in the fields of design and urban planning (Manzini, 2021; Sennet & Sendra, 2022).

In the field of polymer production, this trend became widespread thanks to laboratories experimenting with ideational and creative processes. These processes lead to product design, but also to the conception of technologies, devices, and strategies for recycling and production. These strategies are based on the aforementioned concepts and often combine the phases of collection, recycling, ideation, and production within a single organizational unit, using low-complexity, low-specialization and low-cost technologies (Fig. 2).

The wide diffusion and participation in plastic recycling processes seems to be proportional to the demonisation of this material caused by its misuse for disposable applications. Through excessive functional specialisation (Pietroni, 2014), these applications have exaggerated the incongruence between the post-consumer material's

lifetime and its use time, even when compared to other materials.

Precious Plastic is the global open-source digital commons macro-project that experiments with and disseminates an alternative plastic recycling model. Active in 92 countries since 2013, it defines an “action network” as an ecosystem that enables a global community of people to collaborate on plastic recycling, open design, and open manufacturing projects. This network has produced a new, uniform material and color language that is reproduced almost identically in all nodes of the system, independent of the specificities of the places and contexts in which production takes place. The variability recognisable in Precious Plastic products, as well as in the products of the cases explained below, is due to chromatic differences caused by the unpredictable nature of the recycling process, which combines plastics of different colors. Thus, the recycling production process leaves an expressive mark on the product, which takes on a specific characterisation and finish that symbolically challenges dominant production models.

The various experiments inspired by the Precious Plastic project have evolved the dissemination of this model, for the most part using machines and tools whose level of automation is low, so that the manufacturing process includes manual activities that produce uncertain, varied and random surfaces that materialise in polychromes and irregular shapes, generating this new identity image of sustainability. Subsequently, even industrial or laboratory activities utilising more sophisticated technologies and higher levels of specialisation have reproduced the same aesthetics. This demonstrates the affirmation of a recognisable ecological message endowed upon products with this polychromatic characterisation.

3. Phenomenology of "Thermoplastic Marbling": a mapping proposal

The origin of the use of recycled plastic as a production material can be traced not only to recent Western environmental practices, but also to contexts of emergency and survival where reuse and recycling have historically emerged from primary needs [2].

Starting from these specific contexts and historical conditions, the research develops a theoretical framework and an exploratory mapping project, “Marbled is the New Green,” based on the observation of these phenomenologies. From this map, a new contemporary color code clearly emerges, representing a novel “post-natural” sustainability aesthetics. These new veins and textures of recycled plastics define a specific expressiveness for this material, also reminding of the visual postmodern

experiments carried out in the 1980s—such as the work of Ettore Sottsass and the Memphis Group.

With the aim of mapping the diffusion of the new contemporary code related to polychromies resulting from the recycling of polymer waste, a phenomenological analysis was conducted on the web, and the structuring of a dataset formed the basis for the collection and selection of significant cases at a global level.

The collection of significant projects firstly was carried out by consulting the map available on the *Precious Plastic* website, particularly within the *workspace* category, which refers to initiatives involving experimentation, design, and dissemination of the practice. This was supplemented by research into projects developed by established companies that have promoted this new aesthetic at leading sector events (from design to art). Furthermore, starting from those, the research broadened through a chain reaction that led to the recognition of large and small initiatives, from official websites to dedicated social media pages, to little-known collaborations that contribute to the dissemination of the phenomenon at various levels.

The collection and selection of data determined the structure of a dataset that seeks, within the variety of initiatives, to group together information concerning quantitative and qualitative data enabling their evaluation and the creation of initial thematic clusters specifically combining:

- geographical data concerning the continent and country from which the project propagates;

- quantitative data that relates the presence of projects in the respective country and a selection of these based on specific criteria (see Fig.3);

- qualitative data relating to the type of polymer waste used (often influenced by local needs/issues) and the production technique, whose process varies depending on the context of experimentation and production (from the use of low-complexity machinery in laboratory settings to processes and techniques used in industry).

To date, the research considered 704 projects spread across 93 countries, of which 16 (17%) are in America, 17 (18%) in Africa, 25 (27%) in Asia, 2 (2%) in Oceania, and 33 (35%) in Europe. The selection criteria, based on the ability of each experience to generate real economic/productive or eco-social/cultural impacts through market diffusion, led to the selection of a total of 118 projects, distributed as follows: 43% in Europe, 30.6% in America, 17.3% in Asia, and 4.5% in Africa and Oceania respectively. Furthermore, these are case studies that are not only reaching the market, but also feature a designing or experimental quality that is not limited to the replication

of objects generically attributable to open-source practices, but rather characterise their own production based on the cultural message they intend to convey, the prevailing waste of that particular context, the project designed to respond to specific needs, specific rituals, a specific imagery, or developed based on their technical capabilities or availability in terms of machinery.

The qualitative analysis provided within the dataset, considering materials and production techniques, allows the interpretation of how this colour scheme emerges technically. Although the processes are implemented at different levels of complexity in terms of machinery and equipment, the underlying production technique remains the same in many instances, as is the case with thermo-pressed panels or injection-moulded objects, two production processes that are among the most frequently used both in laboratories and in industry. In terms of materials, on the other hand, there is a prevalence of HDPE (High-Density Polyethylene) and PP (Polypropylene), i.e. polymer waste among those most commonly and daily produced and which are best suited to treatment and processing even in laboratory/craft environments, unlike, for example, PS (Polystyrene), a common waste but more suitable for transformation in specially equipped production environments [3].

These are projects, therefore, that come from different countries and contexts and share not only a globally widespread material resource but, above all, the ethical and aesthetic values of this new colour scheme. Projects that are linked by their ability to transform waste into product, and product into message.

The productive aspect of this phenomenon was then the key to understand the various market levels that such initiatives have reached through the commercialization of their goods, thereby contributing to the global diffusion of this chromatic code as a manifestation of a widespread activism.

Following the initial survey, in fact, it was deemed necessary to expand the dataset from a qualitative point of view with further categorisation based on the different typological areas of application. The production categories identified are: (i) non-industrial/small-scale, (ii) semi-industrial/medium-scale, and (iii) industrial/large-scale. These categories make it possible to interpret the phenomenon across multiple dimensions: production context and impact, project objectives, technological complexity, and productive capacity.

From a typological perspective, instead, projects were observed across four main areas: material and surface design (panels, textures, and finishes), furniture, product, and experimentation both chromatic and material (Fig. 3).

In these domains, plastic is no longer merely a problematic material but becomes a visual language, capable of telling stories of places, communities, and identities.

Specifically, trying to give references to those categories, among the semi-industrial and industrial projects, it is worth mentioning manufacturing companies such as Polygood by The Good Plastic Company (Netherlands) and Plastiz (Italy), where recycled polystyrene is transformed into cladding panels. Despite differences in technique and polymeric base material, architectural components can also be obtained through small-scale non-industrial processes, as it occurs with FabBrick, in France, which produces bricks and surfaces from synthetic textile waste (mostly waste from the fashion industry) using compression and gluing rather than melting (Fig. 4).

In the furniture sector, the transition from non-industrial/small-scale to semi-industrial production is driven by projects that combine social impact, local value, and formal experimentation: in Costa Rica, The Recycle Studio; in Kenya, Flipflop Design, which blends traditional craft techniques and materials with plastic recycling to create furniture and public structures; and in Algeria, Precious Plastic Refugees, which involves refugee communities in the production of school furniture generating educational, occupational, and symbolic value. In these cases, the material quality and chromatic variability of recycled plastic become a powerful narrative medium.

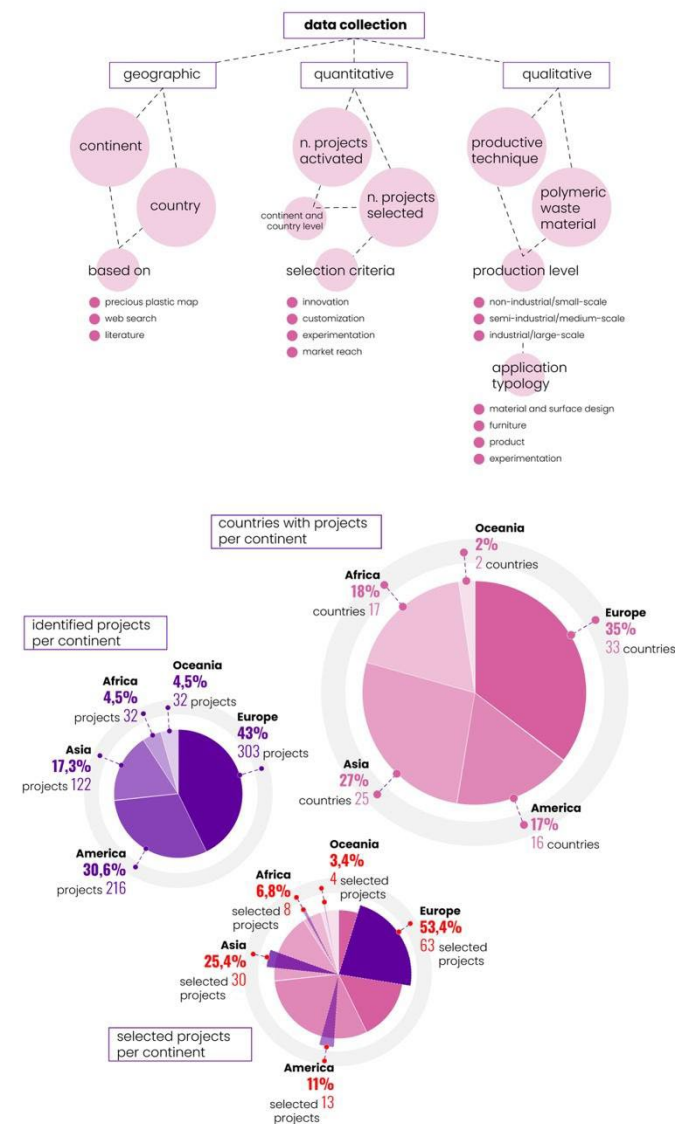


Fig. 3. From top to bottom: Methodology for collection and selection of data for the structuring of the dataset. Quantitative data collected related to the number of countries per continent where projects matching the research intent were found; the number of projects found per continent; the number of projects selected per continent. This numerical data shows, despite the large number of projects, which continents have the highest number of projects meeting the selection criteria.

In the industrial furniture segment, projects like Maximum (France) emphasize user-driven color customization and textured aspects of the process; Samsara (India), Luken by Paola Calzada Arquitectos (Mexico), and Space Available (Indonesia) demonstrate how the “marbled” aesthetic is not just a formal solution resulting from recycling, but a coherent design language: recycled plastic becomes a “noble” material, carefully crafted and returned

to the user as a sign of environmental, social and cultural commitment.



Fig. 4. Finishings. From left to right: Polygood by The Good Plastic Company (Netherlands), Plastiz (Italy), Fab_Brick (France). The first two images show the results of the thermo-pressing process, made by using the “sheetpress” machine. The bricks made by Fab_Brick in the third image are still representing an output of a process that uses pressure but combined with glue rather than high temperatures. The general output given by pressing process of the three projects is related to the “confetti” aesthetics.

In the non-industrial/small-scale product domain, recycled plastic often materializes in small yet highly communicative objects, such as those created by Re=Comb (UK), Sjølove (Norway), and Boomplastic (Poland). As mentioned, this material-chromatic phenomenology has a global scope. Despite this, it is possible to observe practices that attempt to recover an object-based dialogue with local culture. Projects like Precious Plastic Amman (Jordan) or SeyTreasure (Seychelles), for example, exemplify this purpose by designing symbolic objects that reflect local identity and geography, while emphasizing the educational and environmental message of the process (Fig. 5). These laboratories act as a vehicle for information and training for the communities in which they operate.



Fig. 5. Social impact and local identities. From left to right: Precious Plastic Amman (Jordan), Flipflopi Design (Kenya), SeyTreasure (Seychelles). The use of low-complexity technologies enables social projects involving people who are not specialized in productive activities. The projects in the pictures show an aesthetics that is closer to extruded/injected objects, showing a more mixed/shaded color blend related to the marbled aesthetics. Between them, the Flipflopi project, is emblematic in embodying the traditional imagery and manufacturing capabilities related to the territory.

Other experiments fall within the fields of critical or authorial design. The plastic sculptures by Johé Bruneau (Lyon) or the installations by Shahar Livne (Israel), whose bench *Metamorphism: Deep Time* offers aesthetic and philosophical reflections on the evolution of materials across geological time, transforming plastic into a metaphorical, narrative, and critical medium.

Several companies, recognizing the relevance of this emerging aesthetic, have integrated it into their own catalogs, sometimes for dedicated collections or collaborations, generating further diffusion and affirmation of this visual code in the world of product design, furniture and finishes. Camper (Fig. 6), for example, has introduced recycled plastic in the production of shoe soles, encouraging customers to return used ones and to become part of a closed-loop system. In high-end furniture, the collaboration between Heatherwick Studio and Magis led to the creation of the IN-SIDE armchair. In the material and furniture sector, the company EcoPixel promotes this movement by arguing that "we should see products as a precise amount of material that can be re-used for something else" and by spreading the pointillism, exemplified by the Chaise Longue Alex by Alessandro Mendini, as a chromatic and compositional potential in balance between color, shapes and postmodern iconicity.



Fig. 6. Industrial productions. From left to right: Camper (Spain) Roku -2024, Heatherwick Studio + Magis (Italy) In-Side - 2024, Faro Barcelona (Spain) "Lampara confetti". This grassroots aesthetic of sustainability, which began in small workshops and home experiments, now appears to have become well-established, as evidenced by the products shown in these images. It has also been embraced by large companies, which are starting to integrate circular processes to reuse their own waste and produce items that maintain color diversity.

The analysis of mapped projects (Fig. 7) shows that the "marbled" aesthetic has become, indeed, a globally recognized code. At a social, economic and productive level, between informal and industrial practices, between the south and north of the world, between low-tech approaches and industrial processes, plastic is the "common raw material" and is expressed through ever-changing artefacts in a global and interconnected landscape.

4. Conclusions

From the mapping and analysis activities, it clearly emerges the possibility of codifying a new design model for polymeric products that uses color to define a new aesthetic of sustainability. These new ways of manipulating polymers propose new chromatic, semantic and material characterizations which, in a certain way, contribute to educate "to have a new, native aesthetic experience of the sustainable world, fundamental for the transition towards new economic, productive, social and cultural paradigms. The sustainable product will not, in fact, be just a depleted copy of the non-sustainable product; instead, it has to be more beautiful, stronger in aesthetic terms, more convincing" (Caggiano, 2020). To some extent, realizing in a plural and expanded dimension some of Gaetano Pesce's intuitions, these examples go beyond the authorial dimension, and they place chromatic variability as a value of uniqueness and tolerance. They do not demonize plastic, but they understand it and guide it in processes that propose a change of meaning of its own nature. Plastic thus becomes a "human" material, "artisanal" even if not "anti-industrial", "typical" even if still atopic and capable of undergoing both manual transformations and new digital manufacturing technologies. It takes on, in its new condition of only partially controlled polychromaticity, a peculiar and unexpected dimension. This aesthetic condition brings the synthetic material closer to being recognized as a material having its own new naturalness. This condition allows polymers to be capable of symbolizing an holistic model of sustainability that makes aesthetics, ecology, economy and social dimension coexist.

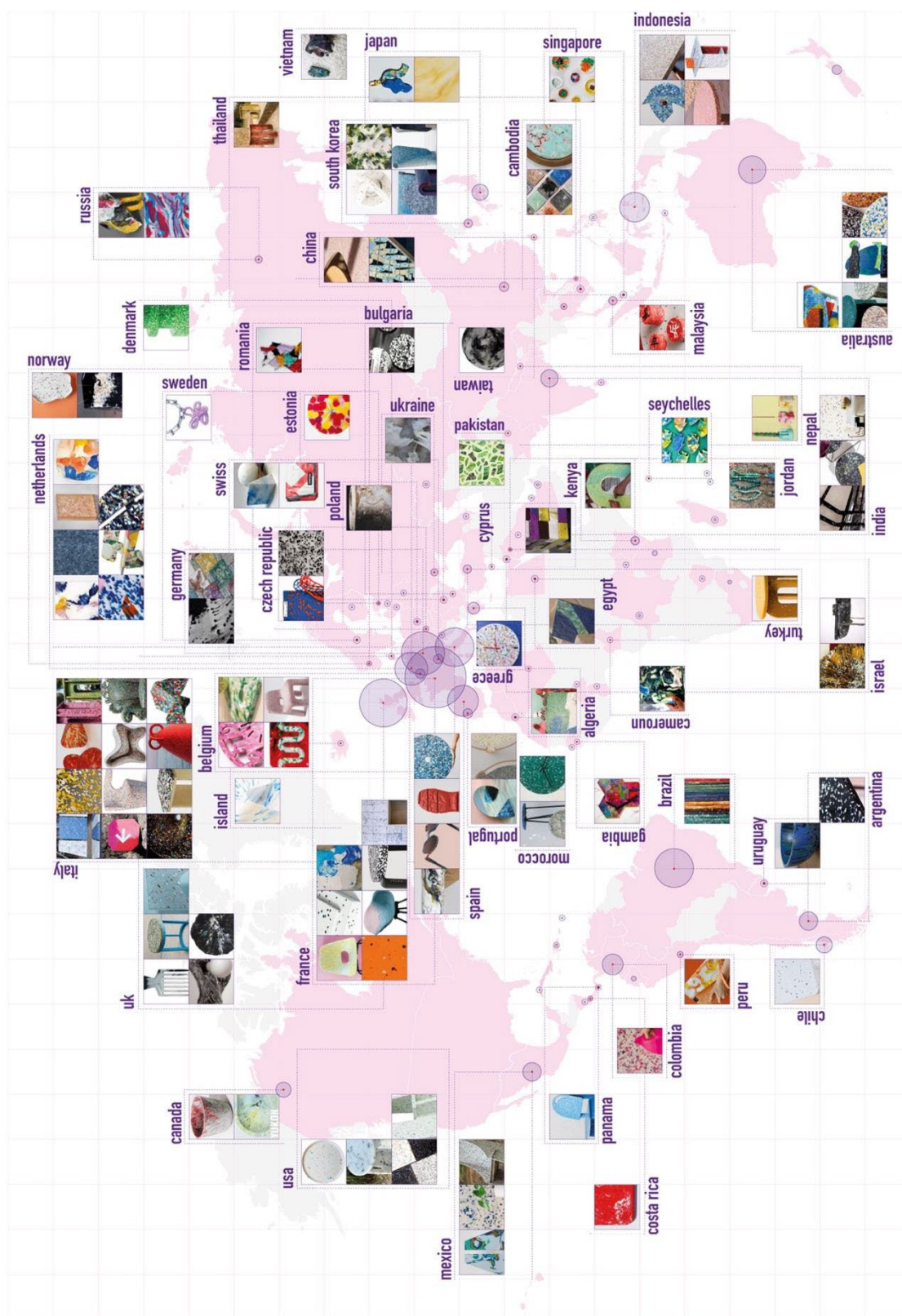


Fig. 7. Global map of selected initiatives. The size of the circles proportionally indicates the quantitative data of the projects identified in each country, of which the selected projects that contribute to the diffusion of the polychromatic code, through their presence - at various levels - on the market, have been highlighted through images.

5. Conflict of interest declaration

The authors declare the non-existence of any actual or potential 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. No financial/personal interests have affected the author's objectivity(s).

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Notes

[1] Although this text is the result of shared work by the three authors, Ivo Caruso did the writing of paragraph 1, Susanna Parlato of paragraph 2, and Iole Sarno of paragraph 3. The abstract and conclusion were produced collectively.

[2] A key example is Cuba during the so-called Special Period - Officially known as the "Período especial en tiempos de paz" - (1991–2000), an economic and political crisis following the collapse of the Soviet Union. In a country that was suddenly isolated and consequently lacking in terms of essential goods and raw materials, the population was forced to reinvent everyday tools and objects, relying on locally available resources

and their own technical skills. This condition led to a form of domestic plastic recycling ante litteram, documented by Cuban designer Ernesto Oroza and French designer Pénélope de Bozzi in their publication "Objets Réinventés". These early experiments represent what the authors call a "domestic industrial production", where objects were produced using aluminum casting, extruded - through the construction of a machine inspired by the one used in churros production - or injected plastic, processes in which the real invention was not the object itself, rather the ingenious adaptation and self-construction of machines built by each "popular creator". As Oroza states: "The need for raw materials converts these places into very selective 'black hollows'. All the plastic objects from the surroundings were absorbed by the mechanism, a kind of industrial cannibalism." (Oroza, 2010). This scenario describes not just a survival strategy, but the emergence of a diffuse creative and productive process, one of the earliest expressions of design based on recycled polymers. Although born out of necessity rather than ecological ideals, the Cuban experience anticipated the kind of distributed production and democratized processes that would soon become widespread globally.

[3] Some projects do not report - on their websites or social media pages - technical specifications relating to the technologies and materials used, which is why it is not currently possible to include them in the dataset in quantitative terms. Nevertheless, within the dataset there is a clear prevalence of the techniques and materials indicated, and in particular for the former, it is possible to detect them from the objects' output, which reports specific features in terms of texture, shape and colour distribution.

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From Functionalism to Eclecticism: the impact of design movements on colour

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ABSTRACT

This article examines the evolution of colour use in fashion and design, beginning with 20th-century Functionalism and concluding with contemporary 21st-century Eclecticism. Throughout the 20th century, artistic and cultural movements profoundly influenced the role of colour, changing aesthetic preferences and shaping collective taste. From Bauhaus and Modernism, which conceived colour as a functional element subordinate to form, to Postmodernism and Eclecticism, which re-evaluated colour as a means of expression and symbol of identity, the socio-cultural context has shaped how colour has been used in design and fashion. The aim is to critically examine the evolution of colour in design and fashion, analysing how different design movements have influenced colour trends and assessing how social and cultural changes have contributed to redefining the use and perception of colour. Through a systematic review of the literature, interviews, and case studies of iconic stylists and designers, the work aims to understand the connections between design, fashion, and culture, as well as the role that colour has played in this process of evolution. The method adopted combines a review of the literature with a qualitative analysis of visual materials and historical documents, as well as an analysis of public statements and interviews already available in the literature. Comparative analysis, thematic analysis, and contextual analysis were employed to explore the use of colour across different historical periods, highlighting the connections between artistic movements and shifts in society's colour preferences. Data triangulation enabled the validation of the results, providing a comprehensive view of colour evolution. The results show that colour, initially relegated to a functional role during Functionalism and Modernism, gradually took on an expressive role during Postmodernism and contemporary Eclecticism. This transition reflects cultural and technological changes that have influenced aesthetic taste and the use of colour as a tool for communication and identity. The analysis also highlighted the importance of sustainability and technological innovations in determining new colour trends. In conclusion, the evolution of colour use in fashion and design reflects a dynamic process influenced by social, cultural and technological factors. Colour has evolved from a simple functional element to a powerful means of expression, capable of communicating identity and cultural values, thereby contributing to the redefinition of contemporary design's aesthetic paradigms.

KEYWORDS Colour evolution, Fashion, Design, Artistic movements, Cultural identity

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1. Introduction

The relationship between design and fashion is not limited to the aesthetic conception of objects and clothing, but also extends to the use of colour, one of the most powerful tools in a designer's or stylist's arsenal. The 20th century witnessed the emergence of a series of artistic and philosophical movements that shaped the use of colour, starting with rigorous Functionalism, characterised by chromatic economy, and ending with contemporary Eclecticism, which celebrates variety and chromatic expressiveness. As Margolin (2017) and Coles (2019) point out, colour in design and fashion has always reflected cultural and technological demands, representing a mirror of a changing society. The history of colour in design and fashion is intimately linked to the social, economic and cultural transformations that have characterised each historical period. The Bauhaus movement, founded in Germany in 1919, played a crucial role in defining the use of colour in 20th-century design. At the Bauhaus, colour was considered a functional element, capable of improving the understanding of objects and creating a sense of visual order (Wick, 2000). This approach reflected the desire to attribute a rational function to colour, as also highlighted by Albers and Itten, whose systematic studies on visual perception influenced the entire Bauhaus colour teaching programme (Margolin, 2017). From a broader perspective, Branzi (2006) emphasises how contemporary design also derives from Modernism's ability to systematise visual languages and codes.



Fig. 1. Original poster from the 1923 Bauhaus exhibition, which uses basic geometric shapes and primary colours to

emphasise the functionality and visual simplicity typical of Functionalism. (<https://popmotif.com/products/bauhaus-austellung-1923-circles-exhibition-poster>)

Johannes Itten (1888–1967) and Josef Albers (1888–1976), both teachers at the Bauhaus, developed colour theories that aimed to systematise the use of colour, limiting themselves to primary colours to emphasise the functionality and visual effectiveness of objects and spaces (Margolin, 2017). As Gage (1999) observes, the colour theories developed at the Bauhaus were not only teaching tools. However, they reflected a broader cultural vision in which colour took on symbolic and psychological meanings as well as functional ones. More recently, some studies have even proposed innovative models of colour perception based on mathematical and theoretical approaches, such as the quantum theory of colour oppositions (Berthier & Provenzi, 2025).

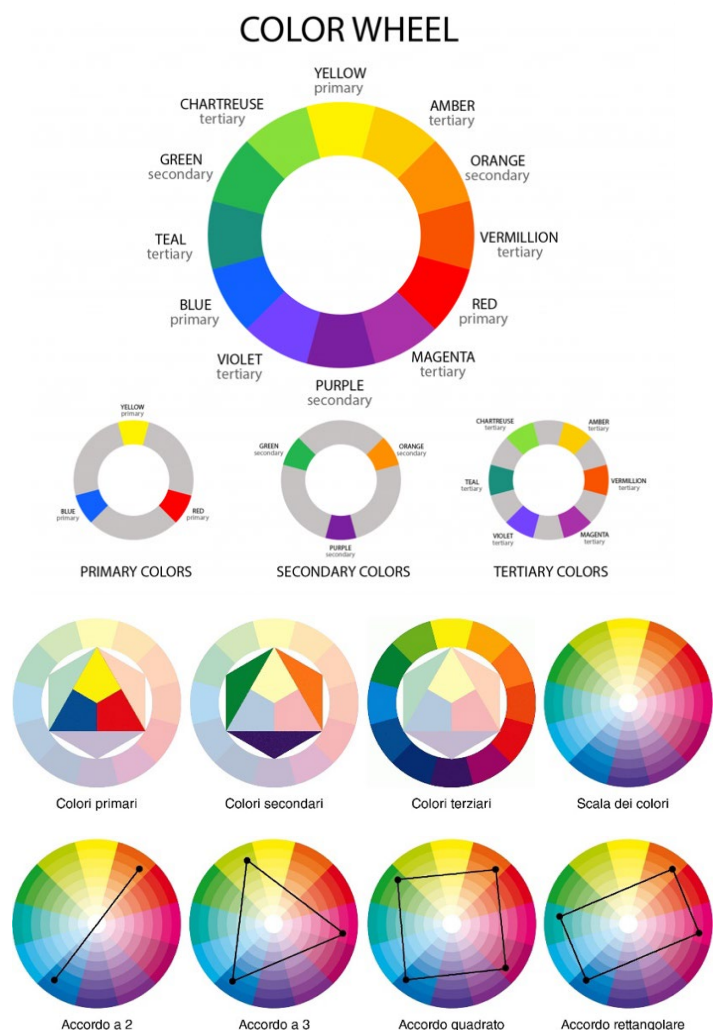


Fig. 2. The color wheel by Johannes Itten (<https://www.color-meanings.com/color-wheel-theory-complementary-colors>)

This view of colour as a rational and functional component reflected the principle that form should follow function, in line with the modernist approach to design. In the years that followed, Modernism further developed this approach. The Modernist movement advocated a minimalist and reduced vision of colour, using neutral shades and limiting the colour palette to emphasise the simplicity and purity of forms. This period saw the emergence of figures such as Le Corbusier, who used colour sparingly, often to create structural contrasts and highlight the architectural elements of buildings (Coles, 2019). In the world of fashion, too, Modernism influenced the use of colour: Coco Chanel, for example, introduced a monochromatic palette of black and white, a symbol of elegance and simplicity, which reflected the essential and functional trends in design at the time. With the advent of Postmodernism in the 1970s and 1980s, colour took on a whole new dimension, becoming a symbol of rebellion against the rigid rules of Modernism. Postmodern designers, such as Ettore Sottsass and the Memphis group, challenged the austerity of Modernism by introducing a range of bright and playful colours, often combined in seemingly discordant ways to create a sense of surprise and irony (Hauffe, 2021).



Fig. 3. A Carlton, a bookcase designed by Ettore Sottsass in 1981 for the Memphis group: an explosion of contrasting shapes and colours as an ironic break with modernist austerity.
(https://commons.wikimedia.org/wiki/File:Ettore_sottsass_per_memphis_srl.,_libreria_carlton,_milano_1981.jpg)

Postmodernism has therefore rehabilitated colour as a tool for personal expression and social criticism, celebrating

complexity and eclecticism in contrast to the modernist emphasis on simplicity (Fiell & Fiell, 2020). As Batchelor (2000) observes, Western culture has long harboured a distrust of colour, perceived as superficial, feminine or decorative. Postmodernism broke with this tradition, restoring colour to a central role in defining identity and criticising modernist paradigms. Postmodernism also profoundly influenced the use of colour in fashion. Designers such as Vivienne Westwood and Jean-Paul Gaultier used intense colours and bold combinations to challenge conventions and celebrate individuality and non-conformity.



Fig. 4. Vivienne Westwood SS21 Editorial. A vibrant palette and unusual colour combinations (lilac and yellow): an emblematic example of postmodernist rebellion against canonical colour rules and individual expressive exploration.
(<https://vogue.globo.com/desfiles-moda/noticia/2020/09/vivienne-westwood-londres-verao-2021.html>)

This trend was also reflected in the fashion collections of the 1980s, characterised by an explosive use of colour,

often in deliberate contrast to the rules of traditional elegance (Geczy & Karaminas, 2018). In the 21st century, with the advent of contemporary eclecticism, colour has become an even more diverse and inclusive element. Eclecticism celebrates the mixing of styles and cultural influences, and colour has been used to express this variety and to represent different cultural identities. Globalisation has led to the discovery and adoption of colours and colour combinations from non-Western cultures, enriching the colour palette of contemporary design and fashion (Quinn, 2019). From this perspective, anthropological studies have demonstrated how traditional clothing and colour systems in non-Western cultures constitute not only an aesthetic repertoire but also a language of identity and symbolism (Küchler & Were, 2005). The work of designers such as Dries Van Noten and Riccardo Tisci reflects this trend, with the use of vibrant colours inspired by global cultures that emphasise diversity and freedom of expression. These European experiences are complemented by equally significant global contributions, such as the technological approach of Issey Miyake and Rei Kawakubo in Japan, the colour palettes linked to Indian tradition by Manish Arora, and the use of Caribbean and Latin American tones in the collections of Oscar de la Renta. These examples confirm that contemporary chromatic eclecticism [1] is a genuinely transnational phenomenon. Interest in natural materials and sustainable dyeing techniques has led to a return to earthy colours and organic shapes, evoking a connection with nature and an ecological sensibility.

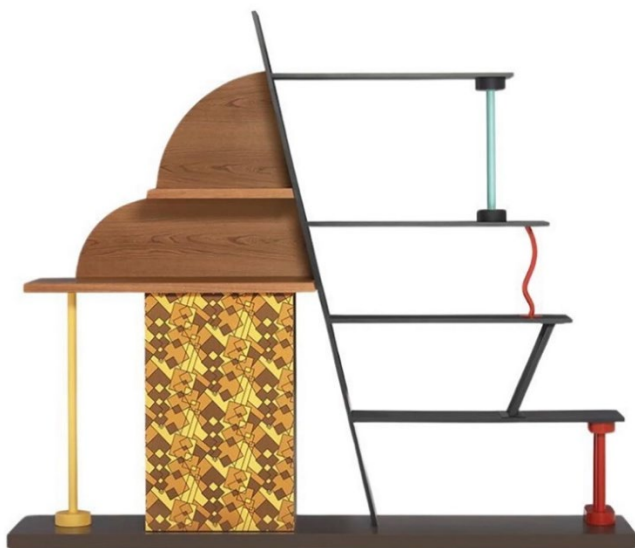


Fig. 5. Sideboard 'Malabar' (1982), another Memphis piece: earthy colours and organic shapes, anticipating the transition to Eclecticism and an interest in natural dyes. (https://www.1stdibs.com/it/arredi/armadi-e-contenitori/stipi/credenza-malabar-di-ettore-sottsass-per-la-collezione-memphis-milano/id-f_24109522/)

This change responds not only to aesthetic needs but also to a growing awareness of the environmental impact of colour choices and production processes. The evolution of colour use in design and fashion reflects the social, cultural and economic transformations that have characterised the 20th and 21st centuries. Colour, once a functional element subordinate to form in Functionalism, has become a powerful means of expression and a symbol of cultural and individual identity, celebrated in contemporary Eclecticism. This work analyses these transformations, highlighting the interactions between various design movements and their impact on colour trends in fashion, emphasising how colour has been used to communicate values and profound meanings in every historical phase (Margolin, 2017; Coles, 2019; Hauffe, 2021).



Fig. 6. Vivienne Westwood SS21. A palette of natural tones and unexpected combinations that reflect a contemporary approach to colour sustainability. The dress mixes textures and colours in an expressive, symbolic and identity-defining way. (<https://vmagazine.com/article/vivienne-westwood-evokes-the-french-rococo-with-autumn-winter-21-collection/>)

2. Objective

The aim is to critically examine the evolution of colour use in fashion and design from the 20th to the 21st century, starting with Functionalism and concluding with contemporary Eclecticism. Specifically, the article aims to understand how design movements have influenced colour trends in fashion, how ideological changes in aesthetic concepts have shaped society's taste in colour, and what role colour plays in communicating social, cultural, and identity values. This study aims to highlight the connections between design and fashion, exploring how artistic movements have influenced colour preferences and the role of colour as both a symbolic and functional element (Coles, 2019; Margolin, 2017). Another fundamental objective is to investigate how social, economic and cultural transformations have interacted with colour trends, influencing the way colour is perceived and used in the context of fashion and design (Quinn, 2019).

3. Method

To develop a critical and comprehensive analysis, a qualitative approach was adopted, based on a systematic review of academic literature and the analysis of selected case studies. The selection of historical movements reflects a predominantly Eurocentric perspective, focusing on Western designers and trends. This choice was motivated by the need to maintain a focus consistent with the evolution of modern and contemporary design in Europe and North America, while leaving room for future cross-cultural explorations. The literature review included recent academic texts, articles from specialised journals and publications on design and fashion movements. The analysis also drew on museum exhibition catalogues and fashion collections from recent decades to establish a solid foundation of historical and contemporary data (Margolin, 2017; Fiell & Fiell, 2020). The main historical movements analysed include Bauhaus, Modernism, Postmodernism and contemporary eclectic movements, to explore how each of them contributed to the chromatic evolution in design and fashion (Branzi, 2006; Hauffe, 2021). A key aspect of the method was the use of comparative analysis to understand the differences and similarities in the use of colour between various design and fashion movements. This approach made it possible to identify recurring patterns and significant differences in the adoption of colour as an expressive and functional element. In addition, specific case studies of stylists and designers were selected, including prominent figures such as Vivienne Westwood and Ettore Sottsass, who incorporated the chromatic influences of historical movements into their work (Geczy & Karaminas, 2018).

The qualitative approach also included documentary analysis of public statements by contemporary designers, collected from secondary sources, previously published interviews and museum catalogues, as well as an examination of visual materials such as photographs of fashion collections and design works, in order to understand the practical application of colour theories (Sudjic, 2020). The analysis of secondary sources was supplemented with historical and theoretical references to trace a complete picture of the evolution of colour from Functionalism to contemporary Eclecticism. In addition, the method included thematic analysis, which allowed for the identification of recurring themes and emerging trends in the use of colour. Thematic analysis was useful for understanding the dynamics underlying colour choices in different historical periods and for highlighting the differences between design and fashion in terms of colour use. This was conducted using a mixed approach, combining inductive coding, which emerged directly from the data collected, with deductive coding, based on theoretical frameworks already established in the study of colour (e.g. Arnheim and Itten). The sources analysed included academic articles, published interviews, museum catalogues and critical texts relating to design and fashion. This procedure was inspired by the methodological model proposed by Braun and Clarke (2006), who define thematic analysis as a flexible method useful for identifying and interpreting recurring patterns within qualitative data. The approach also facilitated the identification of possible connections between artistic movements and changes in society's colour preferences (Quinn, 2019). An additional element of the method was the use of contextual analysis, which took into account the socio-cultural and technological context of each historical period. This analysis provided a better understanding of how external factors, such as industrialisation, globalisation and the growing focus on sustainability, have influenced colour choices in design and fashion. The contextual analysis was developed from a corpus of historical and contemporary sources, including texts on the history of design and fashion, exhibition catalogues, articles from specialist magazines and fashion collections. The time frame considered ranges from 1919, the year the Bauhaus was founded, to 2023, thus including both the origins of Functionalism and the most recent manifestations of chromatic Eclecticism. The approach adopted was interpretative in nature, aiming to relate socio-technical factors — such as industrialisation, globalisation, attention to sustainability, and technological innovation — to colour choices in the design and fashion sectors. In this way, it was possible to highlight how colour is not only an aesthetic element, but also reflects long-term cultural, social and economic transformations. The contextual analysis highlighted the importance of historical context in

the evolution of colour trends, demonstrating how colour has been used to respond to constantly changing social needs and values (Margolin, 2017). The thematic analysis followed a mixed approach, combining inductive coding (emerging from the data) and deductive coding (based on existing colour theories, such as those of Arnheim and Itten). The sources subjected to thematic analysis include academic articles, published interviews and museum catalogues. The contextual analysis covered sources chronologically between 1919 and 2023, including exhibitions, critical articles and fashion collections. The approach was interpretative, aimed at articulating social, cultural and technological factors with the evolution of colour choices. The method also involved data triangulation, combining multiple sources of information to

ensure greater validity and reliability of the results. Triangulation was intended not only as a validation mechanism, but also as an epistemological tool to integrate different points of view and deepen the relationships between design, society and colour. This approach enabled the construction of a more comprehensive and multifaceted view of colour evolution in design and fashion, thereby reducing the risk of bias and enhancing the robustness of the conclusions drawn (Fiell & Fiell, 2020; Sudjic, 2020). To facilitate understanding of the results, a comparative table was drawn up summarising the evolution of colour use in the main design movements and its impact on fashion. The table compares the chromatic characteristics, the function attributed to colour, and some emblematic examples in the two fields.

Period / Movement	Use of colour	Colour range	Function of colour	Examples in design	Examples in fashion
Functionalism (Bauhaus, 1920s–1930s)	Rational, subordinate to function	Primary colours	Facilitating legibility, visual order	Albers, Itten, functional objects	Chanel: essential black and white
Modernism (1930s–1960s)	Restrained, minimalist	Neutral and monochrome	Emphasise form, reduce the superfluous	Le Corbusier: monochrome architecture	Understated fashion, pure lines
Postmodernism (1970s–1990s)	Expressive, ironic, provocative	Bright, discordant colours	Identity and critical tool	Sottsass, Memphis	Vivienne Westwood, Jean-Paul Gaultier
Contemporary eclecticism (2000s–present)	Inclusive, multicultural	Vibrant, ethnic, earthy tones	Visual storytelling, sustainability, emotion	Dries Van Noten, hybrid design	Riccardo Tisci, global and sustainable fashion

Table: summary of results by historical period.

4. Results

The analysis conducted revealed that the use of colour in design and fashion has undergone significant changes, influenced by the aesthetic philosophies of the major movements of the 20th and 21st centuries. During the Functionalism period, particularly with the Bauhaus, colour was conceived in terms of function and efficiency. The use of colour was essential and reduced, often limited to a few primary colours to emphasise the simplicity and functionality of objects and clothing. This approach stemmed from the belief that design should serve a practical function and that colour should contribute to that function rather than being a decorative element. For example, the exhibition “Fashioning Colour” (V&A Museum, 2021) documented the provocative use of colour by postmodern designers such as Westwood and Castelbajac, demonstrating the communicative effectiveness of colour saturation. With the transition to Modernism and, later, Postmodernism, the use of colour in fashion and design began to diversify. Designers began to perceive colour as a tool for communicating emotions, creating identity and breaking with established conventions (Sudjic, 2020). In the 1960s and 1970s, for

example, colour took on a revolutionary dimension: vibrant and contrasting tones were a symbol of rebellion and renewal, both in fashion and interior design. This period marked the beginning of a phase in which colour was no longer simply functional, but took on an expressive and symbolic connotation. An innovative approach mapped these relationships between colour and emotion in art, using fuzzy models to interpret perceptual and cultural variability (Muratbekova & Shamoï, 2023). Nanotechnology has introduced light-reactive materials, such as photochromic and thermochromic pigments, capable of changing their colour based on environmental stimuli. At the same time, bright inks allow the creation of dynamic surfaces, where colour palettes can vary over time and space, radically transforming the concept of colour in design. These innovations have expanded the range available to creatives, allowing for palettes that are no longer static but programmed to adapt to different contexts and interactions (Shamoï et al., 2023; Forni et al., 2025). It is also important to remember that the colours of artefacts preserved in museums undergo alterations over time. To preserve their original colour fidelity, it would be desirable to digitise them using spectrophotometric

scanners at the time of creation, thereby guaranteeing the authenticity of the future colour experience.



Fig. 7. Vivienne Westwood, Spring 2020 Ready-to-Wear. Shocking tones such as orange and red, irregular graphics and visual layering: a collection that iconically expresses the expressive power of colour in postmodern design, in contrast to modernist austerity. (<https://x.com/FollowWestwood/status/1174746083915964418>)

Postmodernism further amplified the use of colour, deliberately breaking with the rules of Modernism and celebrating complexity, irony and kitsch (Hauffe, 2021). Postmodern designers embraced eclecticism, using bold and unexpected colours and combining different styles and cultural references to challenge traditional aesthetic norms. This period saw fashion become a field of colour experimentation, where colour was used to create new identities and challenge conventional taste (Fiell & Fiell, 2020). In the 21st century, with the advent of contemporary eclecticism, the use of colour in fashion and design has become even more diverse and free (Quinn, 2019). Globalisation and the influence of non-Western cultures have further enriched the colour palette, bringing to the

fore colours and combinations that were previously considered unconventional or even discordant (Coles, 2019). Contemporary eclecticism celebrates diversity and individuality, and colour has become a fundamental tool for expressing personal uniqueness.



Fig. 8. Vivienne Westwood, Fall 2016. Multi-layered digital printing and complex colour layering: an emblematic example of the integration between technology and visual colour language in contemporary eclecticism. (<https://vogue.ua/ru/collections/vivienne-westwood-red-label-osen-zima-2016-2017-2237.html>)

Furthermore, analysis has highlighted that colour has become a tool for representing evolving social and cultural values. For example, the growing focus on sustainability has led to a preference for natural, earthy colours, which evoke a connection with nature and reflect a commitment to more environmentally responsible practices (Lazzarini, 2022). Contemporary designers use colours to tell stories and communicate messages that go beyond mere aesthetic value, incorporating themes such as sustainability, inclusivity and diversity (Quinn, 2019). Another aspect that emerged from the analysis is the role of technology in expanding colour possibilities in both design and fashion. The introduction of new synthetic pigments and advanced dyeing technologies has enabled designers to explore colour combinations that were

previously impossible. The use of nanotechnology and bright inks now makes it possible to design colours that are no longer limited to pre-established palettes, but are flexible, interactive and customisable. This has had a significant impact on creative processes, introducing an experimental approach in which colour is understood as a dynamic variable, capable of responding to the context and even to the user's emotions (Mirzaei, 2025; Jonauskaitė & Mohr, 2025).

For example, the use of nanotechnology and digital dyeing techniques has expanded the range of colour possibilities, giving designers new tools to experiment with and create innovative visual effects. This has allowed for greater customisation and made colour an even more central element in building the identity of a product or fashion collection. The analysis also highlighted that changes influence the contemporary approach to colour in consumer psychology. Colours are chosen not only for their aesthetic value, but also for their ability to evoke emotions and create an emotional connection with the consumer. This relationship is confirmed by recent studies that have shown how specific colour characteristics (saturation, brightness, hue) are consistently associated with distinct emotions (Jonauskaitė & Mohr, 2025). This is particularly evident in fashion, where the use of colour can influence the perception of a garment and its ability to communicate a message of cultural belonging or social status (Quinn, 2019). Finally, the influence of popular culture and the media has had a significant impact on contemporary colour trends. Fashion and design are no longer influenced solely by artistic movements, but also by digital culture, social media and global trends. Colour is used to create engaging visual experiences and capture the public's attention in a context where image and visual impact play an increasingly important role (Sudjic, 2020).

Furthermore, colour perception today is strongly influenced by artificial light, digital screen rendering and pigment printing, with repercussions on well-being, legibility and the effectiveness of visual communication. Colour harmony has also proved to be a complex and culturally situated phenomenon, which can be described through fuzzy approaches capable of integrating subjectivity and context (Shamoi et al., 2023). The study revealed that the evolution of colour use in design and fashion has been driven by a complex set of factors, including philosophical shifts, technological advancements, cultural influences, and social transformations. Colour has taken on new meanings and functions over time, evolving from a functional element subordinate to form to a powerful means of expression and cultural communication. As Dries Van Noten stated in an interview with *Business of Fashion* (2022): 'Colour for me is identity. It is the first voice that speaks before one even

expresses oneself.' This statement reflects the conscious use of colour as a cultural and personal marker.

5. Conclusions

The evolution of colour use in fashion and design, from Functionalism to contemporary Eclecticism, reflects the social, cultural, and technological transformations of the 20th and 21st centuries. Colour, initially conceived as a functional element subordinate to form, has gradually taken on a central role in defining aesthetics and identity (Margolin, 2017). Design movements have had a significant impact on colour trends in fashion, influencing aesthetic choices and shaping public taste in terms of colour (Sudjic, 2020). The shift from Functionalism, with its essential and rational approach to colour, to contemporary Eclecticism, which celebrates variety and freedom of expression, represents a radical transformation in the way colour has been perceived and used (Coles, 2019). Several factors, including the evolution of aesthetic theories, social and cultural shifts, and technological advancements, have influenced this change. Colour has become a powerful tool for communicating identity, emotions and cultural values, both in design and fashion. In particular, in contemporary graphic design, colour is confirmed as a key element in influencing perception and visual engagement (Mirzaei, 2025). Contemporary Eclecticism, with its celebration of colour diversity, represents the culmination of this evolutionary process, offering new possibilities for expression and challenging traditional aesthetic conventions (Quinn, 2019). This study contributes to the understanding of the role of colour in design and fashion, highlighting how colour trends are the result of a complex interweaving of artistic, cultural and technological influences. Among the limitations of this research are the absence of statistical analysis and the predominance of references to Euro-Western sources. These elements represent a basis for future research that integrates quantitative methods, cross-cultural studies and interdisciplinary perspectives on colour. Further studies could also investigate the perceptual effects of digital technologies, artificial light and environmental variation on colour reading processes. Emerging technologies, such as nanotechnologies and digital inks, open up new scenarios for the use of colour, which, from a static phenomenon, becomes an interactive and multisensory process. These innovations are redefining contemporary colour palettes and stimulating new design methodologies that combine creativity and materials science.

6. Conflict of interest declaration

All authors declare that there are no potential conflicts of interest.

7. Funding source declaration

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Notes

[1] The term 'chromatic' refers to everything related to colour, its perception, classification or use in a visual context. In theory, the concept refers to the qualitative and sensory dimension of colour, as distinct from its purely quantitative aspects (e.g. brightness or saturation).

[2] The term 'kitsch', of German origin, refers to an aesthetic based on elements considered to be in bad taste, often excessively ornamental, sentimental or artificial. In the postmodernist context, kitsch has been re-evaluated in an ironic and deconstructionist key, becoming a deliberately provocative and unconventional language.

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Chromatic Analysis of the Collective Unconscious: Analytical Psychology Applied to the Art of Antônio Bandeira

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ABSTRACT

Since the dawn of humanity, colors have exerted fascination and influence on the psyche, yet few studies explore their symbolism through the lens of analytical psychology. This research aimed to investigate the extent to which predominant colors in abstract artworks can be interpreted as projections of the collective unconscious. The study is grounded in the premise that artistic choices transcend conscious intent, carrying archetypal meanings. To test this hypothesis, the works of Brazilian painter Antônio Bandeira (1922–1967), a pioneer of lyrical abstractionism in Brazil, were analyzed. A qualitative interpretive methodology was adopted, structured in four stages: (1) artist and artwork selection; (2) extraction of the predominant color palette using specialized software; (3) historical contextualization of the *Zeitgeist*; and (4) symbolic interpretation of colors. The analysis revealed significant patterns: earthy tones associated with archetypes of connection to the land; deep blues evoking transcendence; and vibrant yellow accents, suggesting creative energy. These choices not only reflected avant-garde techniques but also engaged with the cultural climate of the 1950s—a period of reconstruction and the search for new artistic languages in Brazil. Furthermore, the predominance of organic colors over industrial hues reinforced a symbolic connection to nature, aligning with Brazil's broader cultural emphasis on territorial identity. The study concludes that chromatic analysis, when integrated with analytical psychology, offers a robust method for deciphering symbolic layers in abstract art. In Bandeira's case, colors transcend aesthetic function, becoming visual narratives of the collective psyche of his era. This interdisciplinary approach paves the way for future studies bridging art history, semiotics, and analytical psychology, enriching our understanding of creative processes.

KEYWORDS Collective unconscious, Analytical psychology, Chromatic analysis; psychodynamics of color

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1. Introduction

Since the dawn of civilization, colors have held a singular fascination for humanity, operating simultaneously as physical phenomena and psychic experiences. As noted by Pedrosa (2014, p. 20), what appears concrete is "merely a sensation produced by specific nervous organizations under the action of light", a paradox revealing color's dual nature: measurable in its objective aspect yet deeply symbolic in its subjective dimension.

Silva (2006) expands this reflection, emphasizing color's vital role as a "supplement of vital energy, an essential and marvelous part of life" (p. 136). His assertion that "color serves as a pretext for new forms of interaction among beings and between them and the world" (p. 144) anticipates, albeit intuitively, the Jungian conception of chromatic symbols as archetypal language. As demonstrated by Galipeau (1991) and Azevedo (2018), colors constitute a system of signification transcending cultures and historical periods, serving as privileged expressions of the collective unconscious.

Despite extensive literature on chromatic phenomena, studies often neglect their profound symbolic dimension, particularly from the perspective of analytical psychology. This gap is significant, as Jacobi (1959) observes, colors function as the "visual grammar of the unconscious," encoding in their hues the same archetypes manifest in myths and dreams. The Jungian approach interprets chromatic choices not as mere aesthetic preferences but as projections of collective psychic processes, especially in contexts of social transformation.

This study thus investigates the extent to which predominant colors in abstract artworks can be interpreted as projections of the collective unconscious. The analysis proceeds from the premise that Bandeira's palette constitutes a "pigmented collective dream" (Whitmont, 1969), revealing the tensions of a society transitioning between rural and urban paradigms. The methodology combines Jungian analysis of chromatic symbolism with historical inquiry, offering an innovative model for interpreting abstract art as a psychocultural document.

2. Theoretical framework

Carl Gustav Jung (1875–1961), psychiatrist and founder of Analytical Psychology, dedicated his work to the study of the psyche, distinguishing himself through his break with Freudian psychoanalysis in the early 20th century (Hall and Nordby, 2005). His approach sought to integrate theory and clinical practice by exploring the relationship between the conscious and unconscious (Pieri, 2002). Jung argued that his psychology was empirically grounded (Samuels, Shorter and Plaut, 1988), and his model has

been applied across diverse fields, aligning with contemporary scientific paradigms (Penna, 2014).

Building on Freudian foundations, Jung developed the concept of the collective unconscious, distinguishing it from the personal unconscious. While the latter is shaped by individual experiences, the collective unconscious consists of universal, inherited archetypes common to humanity, functioning as the matrix of psychic manifestations (Jung, 1960; Ramos, 2002). This concept relates to the *Zeitgeist* (spirit of the time), which reflects the collective motivations and ideas of an era. Goethe defined it as a set of opinions shaping social thought (apud Caldas, 2004), while Hegel (1986) viewed it as an emanation of the "absolute spirit" inscribed in history (Caldas, 2004). Jung linked the *Zeitgeist* to synchronicity, meaningful connections between internal and external events revealing underlying patterns in human experience (Pieri, 2002; Stein, 2000).

Projection, the mechanism by which psychic contents are transferred onto the external world, is central to this process. Jung (2016) asserted that all reality is psychically mediated, emphasizing that the world exists only through the images we construct. These projections, whether passive (automatic) or active (intentional), play a crucial role in individuation, wherein the subject differentiates from the collective (Jung, 1996).

The unconscious, in its totality, comprises phenomena such as the personal unconscious (repressed or forgotten memories) and the collective unconscious, formed by instincts and archetypes (Jung, 1991). Instincts are innate drives, while archetypes are intuitive perceptual molds shaping human existence. Among instinctual factors, Jung included creativity, which – though related to other instincts (e.g., hunger, sexuality) – can dominate or even suppress them (Jung, 1991). Archetypes, in turn, underpin humanity's "most powerful ideas" (Jung, 1991), adapting to reality through consciousness.

Main (2004) classified archetypes into archetypes-in-themselves (irrepresentable) and archetypal images (expressed in myths and symbols). Aufranc (2006) adds that archetypes manifest bipolarly: in the psychic plane (fantasies, dreams, arts) and the biological plane (bodily symptoms). Symbols, essential in arts and cultures, are "the surface element that substitutes a deeper meaning" (Pieri, 2002). They are not mere conventions but spontaneous expressions transcending rationality (Oliveira, 2017). Cassirer (2005) reinforces that humans inhabit a symbolic universe where language, myth, and art reveal archetypes, offering pathways to comprehend the collective unconscious.

In artistic creation, colors assume a pivotal role. Studied across disciplines – communication (Farina, Perez and

Bastos, 2013), sociology (Erner, 2015), and neuroscience (Barros, 2009) – they are understood as signs integrating cognitive systems (Brandão, 2003). In Analytical Psychology, colors symbolize psychic functions: blue (thinking), yellow (intuition), red (feeling), and green (sensation) (Pieri, 2002; Urrutigaray, 2008). Neuroscientific research corroborates their universality, demonstrating that distinct spectral bands activate specific brain regions, eliciting uniform responses across individuals (Barros, 2009). This finding reinforces the notion of colors as archetypes, culturally variable yet rooted in shared psychic structures (Samuels, Shorter and Plaut, 1988; Fordham, 2002).

Thus, for Jung, color choices in art are not arbitrary but reflect projections of the *Zeitgeist* (present) or anticipations of the future, configuring expressions of the collective unconscious (Guimarães, 2000). Whether in art, myths, or symbols, Jungian psychology provides a theoretical framework for understanding the profound connections between psyche, culture, and human creation.

3. Materials and methods

Building on Jung's (2012, §99) assertion that psychology can investigate the psychic process of artistic creation but not the intrinsic essence of art, this study aimed to analyze colors as projections of the collective unconscious, without engaging in artistic merit evaluations. Accordingly, this research adopted an interpretive qualitative methodology (Sousa and Baptista, 2016), characterized as basic research (Gil, 2008) with exploratory-descriptive objectives. The research design followed an ex-post-facto approach, as it investigates an already established artistic and psychological phenomenon without direct manipulation, instead employing an analysis rich in symbolic and contextual interpretation (Cervo and Bervian, 2002). To this end, the following procedures were implemented: bibliographic research and documental-iconographic analysis, organized into four successive stages.

The **first stage** focused on selecting and analyzing the artist and their works. Considering the Jungian premise that abstract works allow for greater projection of the collective unconscious due to their detachment from representational rules (Jung, 2012), the study examined the production of Antônio Bandeira (1922–1967), a pioneer of Brazilian abstractionism. Seven non-figurative works produced in 1953 were randomly selected: *Paisagem Atormentada*, *Pequena Cidade em Formação*, *A Grande Cidade Iluminada*, *Árvores*, *Favelas em Azul*, *Tela sem título e Abstrato*.

The **second stage** involved identifying the color palette. The digital images of the seven selected works were

grouped into a single image (respecting the screen size ratio), which was then processed using the Color Picker digital tool (<https://imagecolorpicker.com/>) to automatically extract the dominant colors. For methodological rigor, only objective hues were considered, disregarding variations in pigment color (present in the original works), light color (from digital images), and chromatic nuances. Once the palette was defined, a bibliographic review was conducted on the symbolism of the identified colors to correlate them with the *Zeitgeist*.

The **third stage** centered on analyzing the *Zeitgeist* by surveying key historical, cultural, and social aspects of the period (Brazil-1953), organized to facilitate correlation with the previously identified chromatic symbolism.

Finally, the **fourth stage** entailed a symbolic interpretation of the colors, juxtaposing the chromatic symbolism of the derived palette with the era's *Zeitgeist* to establish connections between Bandeira's color choices and the prevailing archetypes of the collective unconscious.

It is important to note that the adopted methodology has certain limitations. Digital color analysis may not perfectly replicate the original tonalities of the artworks, and the symbolic interpretation of colors is subject to cultural variations. However, efforts were made to mitigate these factors by standardizing the color extraction process and grounding the study in established theoretical frameworks, thereby ensuring methodological consistency.

4. Results and discussion

This section presents the findings according to the four methodological stages outlined earlier.

4.1. (Stage 1) Artist and Work Selection

Antônio Bandeira (Fortaleza, Brazil, 1922 – Paris, France, 1967) was an Afro-Brazilian painter, draftsman, and printmaker who became a leading figure in Brazilian Lyrical Abstraction, a movement that revitalized the country's art scene in the 1950s. A self-taught artist, he began painting in the 1930s but developed his distinctive style, characterized by free gestuality and chromatic experimentation, during his stay in Paris (1946–1951) and after his return to Brazil (1951–1954) (Itaú Cultural, 2020).

His work, situated in the postwar context, engages with both American Abstract Expressionism and the *École de Paris*, of which he was part. However, as Couto (2009, p. 87) notes, Bandeira resisted definitive labels, operating instead in the realm of the sensory and ambiguous: "His painting was not affiliated with schools but with a plastic intuition that favored controlled accidents, splatters, and stains as compositional elements" (Couto, 2009, p. 89).

From 1952 onward, he intensified his informal abstraction, producing canvases where dripping and layered textures created a diffuse depth, dissolving the boundaries between figure and ground. Though reminiscent of Jackson Pollock's dripping, Bandeira's technique acquired a tropical lyricism. As Amaral (2007, p. 156) observes: "His use of color – vibrant blues, earthy reds, solar yellows – reveals a luminous atmosphere evoking the Northeastern landscape, even when stripped of literal representation."

Despite his integration into the Parisian art circuit, Bandeira maintained an ambivalent relationship with the artistic nationalism prevalent in Brazil at the time. While artists like Di Cavalcanti championed figuration with local themes, Bandeira pursued a universalist abstraction infused with Brazilian sensibility. Leite (1988, p. 45) analyzes this stance: "His work was not 'national' in subject but in palette and rhythm – a synthesis between the freedom of European avant-garde and the vitality of tropical color."

Bandeira's reception in Brazil was initially polarized: celebrated by critics like Mário Pedrosa, who saw in his work an "organic abstraction" (MAM-RJ, 2017), he also faced resistance from sectors aligned with social realism. Today, his oeuvre is reassessed as a turning point in Brazilian art, anticipating trends later explored by movements such as Neo-Concretism and Informalism.

Thus, Antônio Bandeira occupies a unique place in Brazilian art history: his work bridges the local and the universal, accident and composition. More than an "importer" of abstraction, he was its reinterpreter, forging a language that, in Amaral's (2007, p. 160) words, "was neither French nor Brazilian, but simply necessary." His relevance to this study lies precisely in this synthesizing capacity, making him a key figure for understanding artistic modernity in Brazil.

4.2. (Stage 2) Color Palette Extraction

The colors and their identified nuances that were predominant in the collection of works by artist Antônio Bandeira consisted of four main hues, as specified by their HEX codes: Black (#1D1D18), Blue (#5A6A6E and #7E9092), Green (#A4B480; #85866B; and #6D6449), and Brown (#624B3C; #CEB892; #4D342B; #925638; and #7A412F).

Figure 1 illustrates the grouping of selected works for analysis and the resulting output from the Color Picker palette generation software. The four principal colors and their respective nuanced variations identified as dominant in the collection were determined through HEX code identification and subsequently categorized by hue.



Fig. 1. Works by Antônio Bandeira selected and grouped to extract the color palette using an automated resource.

Jungian analysis attributes profound meanings to colors, interpreting them as archetypal expressions of the collective unconscious. According to specialized literature, the symbolic weight of the four colors can be understood as follows:

Black: Associated with the absence of light and primordial darkness, black symbolizes absolute passivity, primal chaos, and universal substance (Chevalier and Gheerbrant, 2017). In Lüscher's (1969) color test, it represents negation and extinction, projecting shadow contents in psychological assessments. In the alchemical tradition studied by Jung, black (nigredo) corresponds to the initial stage of individuation, marked by confrontation with the shadow and the abyssal unconscious (Ellenberger, 1970). Its symbolism encompasses both negative aspects, such as death, destruction, and melancholy (Farina, Perez and Bastos, 2013), and positive traits, like prudence and wisdom in adversity.

Blue: Considered the coldest and purest of colors, blue evokes depth and transcendence (Chevalier and Gheerbrant, 2017). Edinger (1985) links it to the transcendent function, the psychic process that mediates opposites and fosters wholeness. Hillman (1983) emphasizes its connection to active imagination, representing creative depth and inner reflection. It also symbolizes the divine and the infinite (Farina, Perez and Bastos, 2013), embodying, for Jung (2013), the spiritual process of connecting with the Self. However, it can also express depressive escapism, revealing its paradoxical nature.

Green: The quintessential mediating color, green balances warmth and cold, associating with nature and renewal (Chevalier and Gheerbrant, 2017). Neumann (1954) connects it to the Great Mother archetype, symbolizing fertility and cyclical transformation. Von Franz (1995) highlights its ambivalence: while lighter shades suggest healing, darker tones may indicate toxicity or psychic immaturity. In clinical practice, it is often linked to

hope and emotional rebalancing (Farina, Perez and Bastos, 2013).

Brown: Derived from earthy tones, brown represents materiality and fecundity (Farina, Perez and Bastos, 2013). Jacobi (1959) associates it with the chthonic archetype, tied to telluric forces and corporeality. Whitmont (1969) explores its role in individuation as a symbol of grounding, necessary for integrating unconscious contents. Jung (2013) relates it to the sensation function, emphasizing its role in concrete reality perception.

These interpretations, expanded by analytical psychology scholars, reinforce that colors function as an archetypal language. Galipeau (1991) suggests that their analysis in clinical contexts reveals stages of the individuation process, while Azevedo (2018) demonstrates their application in dream image interpretation. Thus, beyond aesthetic elements, colors constitute complex symbolic systems capable of expressing both individual and collective psychic dynamics.

4.3. (Step 3) Zeitgeist Analysis: Historical-Cultural Context

1953 marked a pivotal moment in Antônio Bandeira's oeuvre, situated within a transformative period best analyzed through Nystrom's (1928) quadripartite framework – events, ideas, attitudes, and technologies as constitutive axes of the Zeitgeist. His chromatic and formal choices during Brazil's "Golden Years" engage with collective archetypes of the era.

The global political economy embodied postwar contradictions: U.S. prosperity (Galbraith, 1958) contrasted with Cold War tensions, while Brazil's developmentalist policies (e.g., Petrobras, BNDE) under Vargas coexisted with dependent industrialization (Furtado, 1961). Rapid modernization, epitomized by Volkswagen's arrival, created stark paradoxes between progress and inequality (Schwarcz and Starling, 2015).

Culturally, the rise of television and radio (Ortiz, 1988) paralleled Niemeyer's modernist architecture. In visual arts, the abstraction/figuration debate (Linhares and Silva, 2016) reflected tensions between universalism and local identity. Bandeira's work, as Amaral (2007) notes, synthesizes "Parisian cosmopolitanism with a chromatic sensibility rooted in Brazilian soil" (p. 134).

Three theoretical lenses illuminate his practice:

Affect Theory (Massumi, 2002): Industrial blues and metallic grays encode nuclear anxiety, while earthy reds map Brazil's transforming landscape (Andrade, 2021). His drips materialize "pre-personal affective intensities."

Cultural Semiotics (Lotman, 1990): His palette functions as a code mediating international abstraction and Northeastern chromaticity.

Archetypal Psychology (Hillman, 1983): Vibrant yellows manifest developmentalism's solar archetype; ochres invoke the telluric.

This tripartite analysis reveals Bandeira's colors as Panofskian "symbolic forms" (1955), condensing midcentury hopes and anxieties. The dialectic between earthy tones and industrial blues visually articulates Brazil's tradition/modernity conflict. Ultimately, Bandeira's work constitutes a chromatic cartography of Brazil's collective unconscious during developmentalism. Through cultural history, affect theory, and semiotics, we decode how his formal decisions materialize the archetypes of an era in flux.

4.4. (Step 4) Symbolic Interpretation of Colors

Antônio Bandeira's 1953 works employ a deliberate palette of cold, opaque tones (brown, green, blue, black), reflecting Brazil's historical transition between rural and industrial identities. This aligns with Singer's (1970) "cultural image," where art embodies collective historical conflicts.

Earthy browns and greens evoke rural roots (chthonic archetype - Jacobi, 1959), while blue suggests transformation (Edinger's 1985 "chromatic transcendent function"). Green acts as a bridge (alchemical *coniunctio*), balancing humanity and nature, a relationship disrupted by urbanization. Black and deep browns reflect social traumas (rural exodus), functioning as "initiator colors" (Neumann, 1954) between archaic and modern structures. They symbolize cultural uprooting and melancholy, echoing Hillman's (1983) "cultural mourning."

The palette's quaternary structure (Jung, 2013) signifies wholeness, with chromatic quartets often representing psychic synthesis in crises (Galipeau, 1991). Bandeira thus captures the Zeitgeist rather than a futurist vision (linked to the number three). As Azevedo (2018) notes, this aligns with 20th-century industrializing societies.

Bandeira's work transcends individual expression, becoming a historical document. As Whitmont (1969) suggests, the palette functions as a "pigmented collective dream," mirroring 1950s Brazil's tensions and paradoxes.

5. Final considerations

This research aimed to investigate the extent to which predominant colors in abstract artworks can be interpreted as projections of the collective unconscious. The results demonstrate that the colors in Antônio Bandeira's abstract works function as archetypes that project the collective

unconscious, revealing the Brazilian Zeitgeist of the 1950s. The analyzed palette - brown, green, blue, and black - constitutes a symbolic system that reflects the tensions of a society transitioning between rural and urban realities, confirming art's psychological function as a social mirror.

The findings provide significant contributions to both the creative process and art therapy. Regarding creative practice, they suggest that chromatic selection transcends individual preferences by connecting with archetypal patterns. For art therapy, they expand the interpretation of colors beyond expressions of personal emotional states to include collective psychological processes.

While the focus on abstract works has privileged the analysis of archetypal content, future research could expand the investigation in two key directions: First, by examining figurative works from the same period to test the hypothesis that abstraction facilitates the emergence of the collective unconscious. Second, through comparative studies with artists from other industrializing nations, which might reveal universal patterns in chromatic choices during periods of social transformation.

The Jungian approach developed here proves particularly potent for deciphering chromatic codes that, while apparently subjective, engage in dialogue with universal psychic structures. This confirms that Bandeira's art operates simultaneously as historical record and timeless expression of the collective unconscious. Consequently, this analysis provides a replicable model for interdisciplinary studies bridging psychology, art, and social sciences, highlighting color's.

9. Conflict of interest declaration

There is no financial or personal conflict of interest that could have affected the authors' objectivities.

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Film Laboratory Manuals as Sources for the Reconstruction of Colour in Silent Film Restoration.

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ABSTRACT

Documentation is a fundamental phase of the film restoration process, essential for collecting information that supports decisions taken throughout the workflow. Sources may vary depending on the specific restoration project and can include film elements or film related materials such as photographs, posters, press clippings, ephemera, music scores, screenplays, censorship or copyright documents, technical documentations, archival and bibliographical references. Among these, film laboratory manuals represent one of the sources especially for technical information. In particular, this contribution focuses on the use of laboratory manuals as a reference for colour restoration of silent films.

Chemical formulas contained in manuals can provide critical information for the conservation, reconstruction, and restoration of historical colour processes. As with other sources, laboratory manuals must be cross-referenced with the other documentation collected for the project to ensure their reliability. A particularly effective approach involves comparing colour formulas with the results of scientific analyses conducted on film materials.

Understanding the nature of colour through scientific analysis is useful from both conservation and restoration perspective: identifying the composition and degradation of colourants contributes to make a better long-term conservation plan and allows a more accurate characterisation and reconstruction of original film colours. Moreover, comparing analytical data with historical formulas provides information for the development of a reference database to support future restoration projects.

As a case study, this contribution presents the recent collaborative research by the Cineteca Nazionale and the Chemistry Department of the University of Milan, introduced at the XIX Colour Conference 2024. The research applied spectroscopic analyses to the most common silent-era colouring techniques (pochoir, tinting, and toning) and compared the results with corresponding formulas published in laboratory manuals of the time.

KEYWORDS tinting; toning; pochoir; film restoration, colour restoration, spectroscopy.

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1. Introduction

The film restoration process is a complex operation that requires extensive documentation involving various sources from the analysis of available film elements to the study of film related materials all selected according to the most appropriate workflow. Similarly, the sources of information for the colour restoration varied on case-by-case basis.

Silent films were coloured using various techniques, the most common were pochoir tinting and toning, which we discuss in detail in Section 2.1 of this contribution. In the specific case of reconstructing of silent film colours, a primary source could be other film materials, such as positive prints. However, it is rare from this period of film history find two positive copies of the same version and print generation.

Film materials include also negatives that in some case contain indications for colouring positive prints. An example is in figure 1, a frame from an anonymous film shoot around 1915 and sent to the Ambrosio Film laboratory in Turin for the development of the negative and the printing of a positive. From the word “arancio” written in the first frame at the beginning of the scene, we assume that the positive was meant to be tinted in orange.



Fig. 1. Negative frame (author's private collection).

This indication is not enough: the colour could have been changed later during the workflow and even if it had been orange we cannot determine the exact shade.

Film related sources could include books as laboratory manuals, photos, posters and press clippings, ephemera, music sheets or screenplays with indication of the colour for each scene, film reviews, administrative documents with instruction for film laboratories and working samples or copyright books. The last two are particularly interesting because usually contain samples directly from a positive coloured print. Working samples are cardboard album with frames applied as visual trace for editing, insert intertitles and as reference for colours [1]. Similarly, copyright books, as the example in figure 2, are detailed description of a film with a frame for every scene usually from a coloured positive print [2].

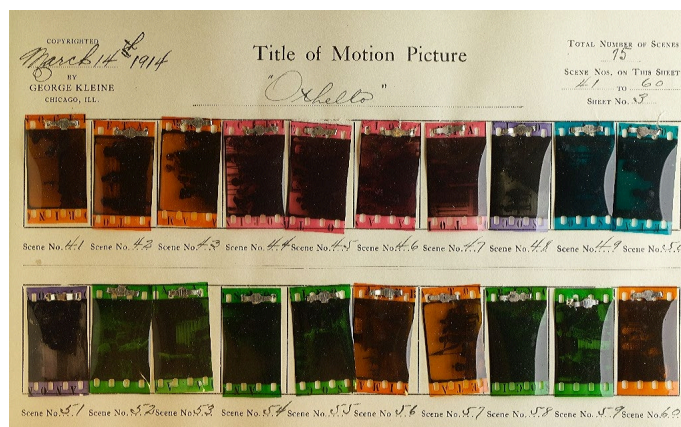


Fig. 2. A page from a copyright book (Timeline of Historical Film Color and Library of Congress).

In recent years, alongside these traditional sources, scientific analyses, especially spectroscopic techniques, have become more common for the characterisation of film bases, emulsions, and colourants.

These are just some examples, documentation sources vary depending on the subject of the restoration and must have compared each other for mutual confirmation and for supporting restoration decisions.

Laboratory manuals can be one of the sources for colour reconstruction. However, as for other documentation, the formulas they contain must be cross-referenced. One of the most interesting comparisons is between manual formula and the results of scientific analysis of colours.

Following, a brief description of the main colouring techniques and of four representative laboratory manuals in use in the silent era. In Section 3, an overview of scientific studies on film colours followed, in section 4, by a case study from a research project of the Cineteca Nazionale in collaboration with University of Milan presented at the XIX Colour Conference (Rossetto et al., 2024).

2. Laboratory Practice and Manuals

A film laboratory is a technical facility for the film industry where specialists develop, print, and conform materials for productions and distributions. Film laboratories develop camera negatives, make negative and positive intermediates and at the end of the process print positive copies. Since the early days, the processing steps for the many different types of film are similar in principle, though there are variations in specific solutions and treatments.

Laboratory manuals from 1900 to 1929 contain all the information on film processing and colouring techniques are one of the topics covered. Often, in addition to the description of the process, there are also formulas for

preparing dye baths, indications of temperatures, duration of the immersion and sometimes also samples of the results.

Manuals are indeed a useful source of information for film colours, but they gave general indications, and all the labs could modify the original formulas according to specific requests. For this reason, while they can be a good reference for colour restoration, formulas must be confirmed by other sources.

2.1 Historical Techniques for Silent Film Colouring

In the silent era, films were coloured using a variety of processes, many experimental, some never actually applied, and others used just for few films. For an in-depth study of all these techniques, including samples and literature, the main reference is the online database *Timeline of Historical Film Color*, created in 2012 by Barbara Flueckiger and her collaborators (Flueckiger, 2012 ff.), alongside the recently launched *Film Atlas* (Layton, 2025 ff.). Despite this vast variety of experimentation, pochoir, tinting and toning were the most common techniques because they were simple to achieve and could be standardised to fit in the workflow of film laboratories.

The first technique, in chronological order, is pochoir or stencil colour (an example in the frame in figure 3) obtained by colouring defined areas of the images frame by frame. Initially, frames were coloured by hand, a method that directly descend from photographic retouching and magic lantern slide painting. Colours were applied manually by hundreds of women [3] using stencil then, to speed up the process, by machines with a continuous velvet band saturated with colour dye.



Fig. 3. Pochoir colours (Brian Pritchard website).

Despite this improvement the pochoir process remain too slow and expensive, whereas the other two techniques, tinting and toning, were more successful and lasted longer. Tinting, in figure 4, is obtained by immersing the positive print into dye baths (the composition and proportions of which changed according with the colour) and homogeneously attaches over the entire film including the perforation area, darker parts remain black.



Fig. 4. Blue tinting (Brian Pritchard website).

There were also pre tinted positive film stocks commercialised in the 1920s by, among others, Kodak, Agfa and Pathé. The base of the positive film was not transparent but coloured, and the result was similar to tinting method, although this kind of colourisation was marginal.

Toning is a process obtained by immersing a positive print into a dye bath (that, also in this case, change according with the colour) where a chemical reaction replaces the neutral silver image with one consisting of coloured metal compounds. In toning, as shown in figure 5, the film base remains transparent, and the image is coloured.



Fig. 5. Copper toning (Brian Pritchard website).

Pochoir, tinting and toning were all applied on positive prints. These three techniques could be combined.

2.2 Manuals

Laboratory manuals chosen as examples for this contribution come from different geographical areas and were printed in different years, to provide an overview of the types of publications available during the silent era. All these manuals collect recipes from earlier sources and fixed practices already in use in film laboratories.

2.2.1. Guida pratica alla cinematografia (1916)

The first manual in chronological order is Vittorio Mariani's *Guida pratica alla cinematografia* (Mariani, 1916). The section thirteen is dedicated to film colourisation formulas

for tinting and toning considered part of broader process. Indeed, Mariani takes a comprehensive view of film production and covering almost all the activities connected to the film industry of the time from the construction of a studio and shooting to laboratory treatments and projection. When the film industry grew all these activities were separated in specific branches (as they still are today) but at the beginning of film history they were often integrate in one facility. Mariani also write about pochoir which he discourages from adopting, considering it a long and expensive process not necessary for a modern film laboratory. Mariani refers to the practices in French and Italian labs, with many references to the production chain of Cines, company founded in Rome in 1906 (the manual is dedicated to Alberto Fassini, the studio director) and to Lux film lab, active in Paris from 1906 to 1913.

The following three manuals are different from the Mariani's as they are from the three main film manufacturers of the time: Kodak, Agfa and Pathé and specifically think for their products.

2.2.2. Tinting and toning of Eastman Positive Motion Picture Film (1918)

The first edition of *Tinting and Toning of Eastman Positive Motion Picture Film* was published in the United States in 1918 (Kodak, 1918) and, with subsequent re-edition, until 1927. This manual is specifically designated to colour for Kodak films. In the preface of the second edition, issued the same years as the first, the anonymous author writes that a revision was necessary due to the difficulty of obtaining foreign dyes for film as indicated in the previous version of the manual. Thanks to tests of the National Aniline & Chemical Company of New York the author can now recommended American products that are equal in every aspect to the one obtained abroad. The manual also provides a section of samples with frames from tinting and toning positive prints (figure 6).

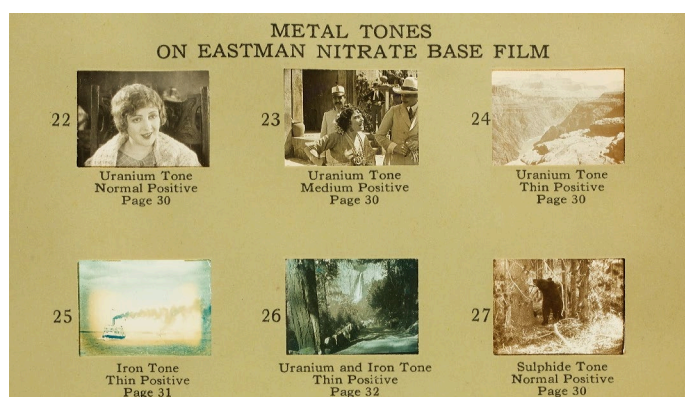


Fig. 6. Cardboard from *Tinting and Toning of Eastman Positive Motion Picture Film* (Timeline of Historical Film Color).

2.2.2. The Agfa Kine Handbuch

Agfa Kine Handbuch, published in Germany in 1925 (Agfa, 1925), is the main reference for Agfa's film products. It is worth underline that AGFA (an acronym for Aktiengesellschaft für Anilinfabrikation) was founded in 1867 as a manufacturer of aniline-based dyes and stains, which were also the base of colourants used for photography and film. In 1903, Agfa began producing its first cinematographic film, and by 1925 had become one of the main film production facilities in Europe. The Kine Handbuch contains, an extensive section dedicated to film colours that include, as the Kodak manual, a substantial collection of frames on cardboard as samples for showing tinting and toning and their combined effects. In figure 7, one of the cardboards with example of tinting frames with the correspondent colour formula.



Fig. 7. Cardboard from *Agfa Kine Handbuch* (Timeline of Historical Film Color).

A detail of the yellow / orange tinting sample (in the figure 7 indicated as farbe nr. 6) is reproduced also in figure 12.

2.2.3 Le film vierge Pathé. Manuel de développement et de tirage

Le film vierge Pathé. Manuel de développement et de tirage (Pathé, 1926) illustrates all the laboratory work carried by Pathé at Vincennes with detailed description of procedures for developing, printing and colouring film. The colouring process is described in the section ten dedicated to the development of positive prints. This section covers all the techniques, particularly tinting and toning and is focused on Pathé products as dye baths or pre tinted films. The manual contains formulas, but process isn't described in deep. For this reason, Jessie Martin (Martin, 2013) in his study on colour in silent cinema from the point of views of film manufacturers, writes that this publication seems more geared towards promoting Pathé products than providing useful information for professional. *Le film vierge Pathé* also present samples from positive prints on cardboard (figure 8) similar to those in Kodak and Agfa manuals.



Fig. 8. Cardboard from *Le film vierge Pathé* (Timeline of Historical Film Color).

3. Scientific studies applied to film preservation and restoration

The different activities related to film conservation, preservation, and restoration have developed in relative isolation and have only recently been connected to the broader field of cultural heritage conservation practices. Paolo Cherchi Usai write that the main reason of this isolation and lack of scientific studies is due to the short history of the medium and to the “idea of moving image carriers represents an ‘art of reproduction’ and therefore do not possess the ‘uniqueness’ required to warrant the conservation treatment given to other artifacts” (Cherchi Usai, 2010).

For this reason, non-invasive and micro-invasive analysis, common practices in the cultural heritage field have been very rare in film conservation and have only recently been adopted. According to Cherchi Usai the change occurred with the transition to digital technology in film preservation and restoration, when analogue film materials acquired the status of unique objects previously denied to them.

As result of this change in perspective the interest in scientific studies applied to films materials increase. Examples include research from the IPI (Image Permanence Institute of the Rochester Institute of Technology) or from the Berlin University of Applied Sciences (HTW Berlin) [4] and the growing use of spectroscopic analysis among film archives as part of documentation for film preservation and restorations. Recently, the working group “Preservation/Restoration

Documentation” of the Fiaf (Fédération Internationale des Archives du Film) included a dedicated section for “spectroscopical analysis” in its guideline for documenting film restoration process [5]. The addition of this session shows the improvement of this practice in the film archive community for identify film bases, reconstruct colours and assessing deterioration levels.

In parallel the specific field of colour analysis has been increased. The mentioned website Timeline of Historical Film Color (Flueckiger, 2012 ff.) is also a valuable resource for both old and new research and case studies on colour analysis. For example, the website feature results of the recent research project of the University of Zurich and HTW that microscopically investigated in transmission and cross-sections film material from Koshof Collection [6]. Another example is the study of the Pathé metal and mordant toning in the films of the Turconi collection carried by Ulrich Ruedel using the x-ray fluorescence (Ruedel, 2017).

Colour analysis is an essential tool both for conservation and restoration of films. From the long-term conservation perspective, understanding the nature of the components of a colour and how they decay is important for creating a better long-term preservation plan. From the perspective of the film restoration (whether photochemical, digital or hybrid), it is relevant for a more precise characterization and reconstruction of colours. For example, the frame below (figure 8) is an unknown Ambrosio film, with a faded yellow tinting and traces of another colour on the side. In this case we have an isolated fragment, and we don’t have a colour reference in other scenes, so we don’t know the shade of the original yellow (light yellow, orange / yellow, acid green / yellow etc) and if the red in the side is a trace of the colour from another scene or another kind of pigment.



Fig. 9. Yellow tinting frame (author’s private collection).

In other cases, the colour is not visible or only few traces remain as in the frame in figure 9 from the Pathé film *La naissance de Vénus* (1897 – 1899 ca): the shell was hand coloured, and some traces are still present, but we don’t know if it was a yellow or an orange and if there were other colours no longer visible.



Fig. 10. Frame from *La naissance de Vénus* (AIRSC film collection).

In digital preservation and restoration, the use of scientific analysis is essential for setting rigorous digitization strategies and for interpreting the signal of colours registered by film scanners. An example for scientific analysis applied to the digitization workflow is the mention research on the Koshof Collection (Trumpy et al., 2021). The MIPS Lab, in the Department of Informatics at the University of Milan, has been conducting research in this field for several years. One particularly interesting study focused on the digital restoration of degraded colours, using a prefilter based on a fading model derived from the analysis of deteriorated film colours (Rizzi et al., 2008). Recently, the hyperspectral imaging technique has been used for acquiring, restoring, and preserving the colours of damaged positive films. This technique was applied to *Ivan Turbincă*, a film produced by the Romanian studio Animafilm in the 1980s, (Nobili et al., 2025) and it shows potential for application to silent film colours as well.

4. Manual formulas and spectroscopical analysis: The Case of the Yellow Tinting of an unknown French silent film

An example of research that compare colour recipes contained in laboratory manuals with the results of non-invasive and micro-invasive methods is the one presented at the Color Conference in 2024 by the Cineteca Nazionale and University of Milan (Rossetto et al, 2024). The aim of the research is to understand the real components of colours and compared them with the original formulas. All the information collected in the research will serve as a guide for characterizing colour, understanding colour deterioration, and establishing better conservation and restoration strategies.

The frames selected for this research are five, all from French and Italian films to have a precise comparison with the colour formulas contained in two manuals used in these areas: Vittorio Mariani *Guida pratica alla cinematografia* and *Le film vierge Pathé. Manuel de*

développement et de tirage. An additional reference is the *Agfa Kine-Handbuch* to highlight similarity in formulas for the same colours. All these manuals are previously described in section 2.2.

The colours of the five frames (pochoir, tinting and toning) were analysed by different spectroscopic techniques with non-invasive and in some cases micro-invasive methods.

Raman spectroscopy was applied in micro mode and with low incident power to preserve the highly flammable cellulose nitrate film support. Raman is a non-invasive analysis based the inelastic scattering of radiation by the sample molecules and associated with molecular vibrations. For this reason, Raman is a technique allows to univocally recognize the analysed compound. The micro-Raman spectra were acquired using a Jasco TRS 300 triple monochromator spectrometer, equipped with an Andor CCD detector and interfaced with an Olympus BH-2 microscope. A Cobolt Twist TM 25 laser with emission at 457 nm (blue) was used as excitation source. The spectral region 800-1800 cm^{-1} was considered.

To overcome the fluorescent emission that could hide the signals in the final spectrum (one of the major limitations in Raman), surface-enhanced Raman spectroscopy (SERS) was also used. SERS is a micro-invasive technique, in which the signal is amplified by the interaction between the analyte molecules and a nanostructured metal substrate. If a selected excitation wavelength that corresponds to the absorption band of the sample is used, a further amplification is observed due to the resonance effect. In this case a colloidal suspension of silver nanoparticles was used, prepared according to the Lee and Meisel procedure (Lee et al., 1982-86). The analysis was conducted using a micro-Raman probe equipped with a notch filter and an Olympus 50X objective, connected to Lot-Oriel MS 125 spectrometer. The probe is also connected to a laser source with emission at 532 nm (green).

To perform the analysis, a micro-sample was taken from the perforation area by scratching the film with a scalpel and the powder was placed on a glass slide with a drop of the solution containing the colloid and an aggregating agent (sodium perchlorate).

The absorption spectra in the UV-visible spectral region of the five frames were acquired as well. It is a non-invasive technique useful for the study of compounds that impart colour thanks to the presence of chromophore groups in the molecular structure. The analysis was conducted in transmission mode using a Jasco V-570 benchtop spectrometer with an acquisition range from 350nm to 800 nm. Unlike the Raman spectrum, the absorption spectrum has broad bands and therefore is not specific for a given compound, but allows for some important considerations,

such as the use of mixtures rather than pure compounds in the colour formulation. Finally, to study the colour of the blue-toned film, Fourier transform infrared (FT-IR) Spectroscopy in specular reflection was used using a compact Alpha spectrometer from Bruker. The measurement was carried out on an area of approximately 6 mm in diameter on the emulsion side of the frame.

Following, an example of the methodology applied on a specific sample: a yellow tinting frame from an anonymous French film.



Fig. 11. Yellow tinting frame (author's private collection).

The frame is print on an unknown film stock, datable post 1909 due the presence of the KS (Kodak Standard)

perforations introduced from that year. The photographic sign of perforation from previous film materials indicate that is not a first generation print but a following copy. The colour of the frame is a yellow tinting.

For this frame, the use of an orange dye was at first hypothesized from the Uvvisible spectrum despite the yellowish colour of the film. In fact, its absorption maximum is located at about 480 nm, while the yellow dyes normally used for tinting absorb at slightly lower wavelengths (AAT Bioquest, Inc., 2024). The concrete assumptions about the nature of the dye used for the tinting were possible through the SERS technique which made it necessary to take a powder sample in the low perforation area. The obtained SERS spectrum shows clear analogies in the trend and intensity of the signals with a SERS spectrum of the Orange G dye (Acid Orange 10), a synthetic mono-azo dye attested for use in tinting formulations in several manuals. For example, Gregory in Motion Picture Photography (Gregory, 1927) registers a list of standard dyes which have been chosen as fulfilling the tinting conditions as nearly as possible and the Orange G is one of them for the "Cine Orange" tint. The use of this dye is also attested in the Agfa manual (Agfa, 1925

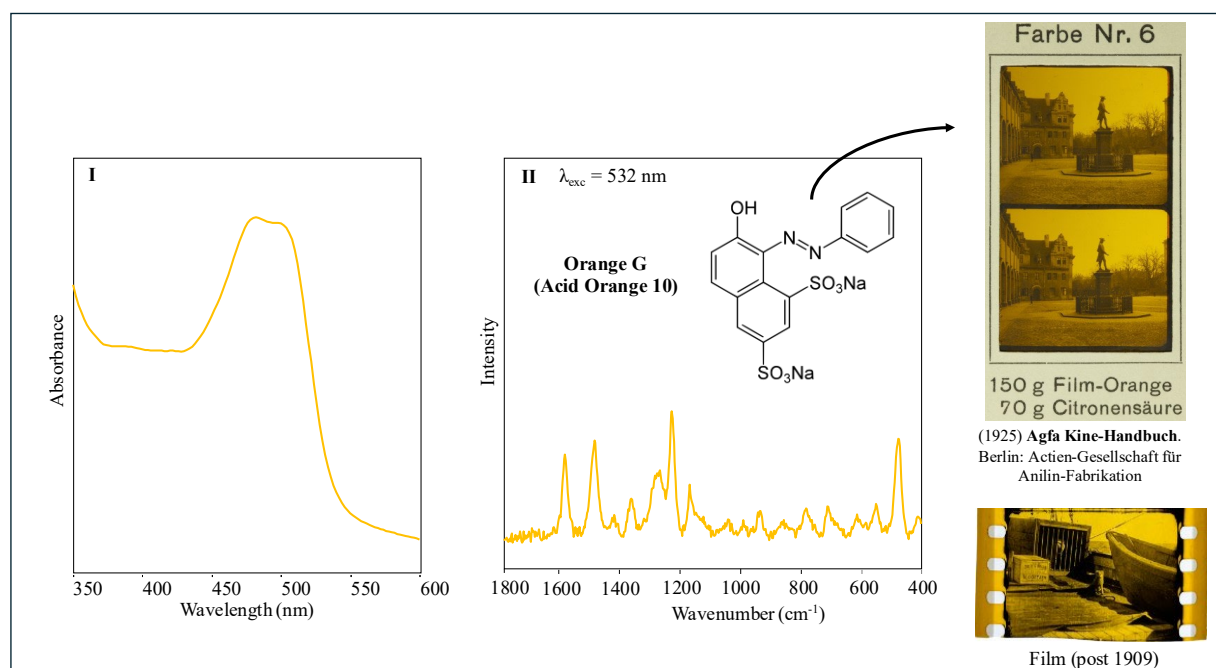


Fig. 12. UV-visible (I) and SERS spectrum (II) with identification of the dye in the sample with a yellow tinting (conference proceeding Silent Film Colourisation Process: From Recipes to Film Laboratories).

5. Conclusions

In the case study of the Cineteca Nazionale and University of Milan, the application of non-invasive and/or micro-invasive analytical methods to the study of the colour of silent films has been useful to obtain some important information. First, for most of the samples, these methods

have enabled us to uniquely identify the dyes used in the tinting formulations, finding a direct correspondence with the historic manuals available in the literature. In cases where the dye has not been identified, because of the impossibility of taking a sample or due to the overlapping of tinting and pochoir, these techniques still allowed the

identification of the chemical family to which the dye belongs. Micro-invasive methods confirmed some hypotheses based on the results obtained by non-invasive ones, validating their effectiveness as well.

As previously wrote, the study and the identification of synthetic dyes used during the silent era is fundamental for film conservation and restoration. Moreover, in the context of the ongoing debate around both photochemical and digital restoration of audiovisual heritage, the results of these analyses could be an important starting point for creating a database of technical data available for restorers aiding in the reconstruction of original colours.

Some databases collecting technical and sensitometric data on films are available, particularly for sound films. Examples include the FIAF Madrid Project, based on technical sheets and labels from manufacturers, and the similar Photo Fire2 [7]. The next step could be to match the collected documentation with scientific analyses of the same film materials.

Spectroscopic data can provide the colorimetric coordinates, essential for digital restoration. Furthermore, due to the frequent lack of clear references in the literature, analyses of this kind help clarify the types of dyes used in historical film laboratory process enriching the documentation collected for a restoration project.

These results demonstrate how scientific analysis can serve as a valuable resource in preparing a film restoration project, corroborating, and confirming formula in laboratory manuals as well as film related sources, archival and bibliographical documentations.

6. Conflict of interest declaration

The author declares no conflict of interest.

7. Funding source declaration

The author declares that any funding or research grants (and their source) received in the study, research, or assembly of the manuscript.

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9. Biography of the author

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Notes

[1] Working samples from Itala Film laboratory were presented by Stella Dagna at the 2020 Domitor Conference available at: <https://domitor2020.org/en-ca/the-working-samples-function-and-accidental-beauty-from-italian-silent-cinemas-manufacturing-machine/>

[2] Examples preserved at the Library of Congress, as the one reproduced in figure 2, and available on Timeline of Historical Film Colour website.

[3] During the silent era, women were in charge of hand colouring film in all labs. They entered the film industry from photographic studios where they retouch photos, and before from magic lantern slides or miniature paintings. The reasons for this preference are not clear and exist several hypotheses. One is that women are more precise than man in these activities, while another is that their works was cheaper, which was an important factor for an activity that requires long hours of labour. For an overview, with a focus on the case of Cines in Rome, see Pierotti Federico, *Colorare le figure. Il lavoro femminile sulla pellicola* (Bianco e Nero, n. 570, maggio – agosto 2011, pp 111-118).

[4] In 2017, during Il cinema ritrovato film festival, Ulrich Ruedel, professor at the HTW Berlin held a workshop for the Fiaf Technical commission titled "Analyzing Color Processes with Scientific Tools: Multicolor / Uficolor / Sirius Color" in which he discussed the approaches employing methods of using these classical conservation and restoration disciplines (as X-ray Fluorescence, spectroscopy and classical visual microscopy) in the moving image field.

[5] The Preservation/Restoration Documentation Task Force of Fiaf was borne inside the Cataloguing and Documentation Commission with the addition of support members from the Technical Commission. For more information on the project, result and future development: <https://github.com/FIAF/preservation-restoration-events/>

[6] Images are available on Timeline of Historical Film Colour website https://filmcolors.org/filter/?_sft_ubercategory=htw&post_types=gallery

[7] Fiaf Madrid Project <https://www.fiafnet.org/pages/Divers/The-Madrid-Project-Intro-en.html> and Photo Fire2 <https://mips.di.unimi.it/photofire/>

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Monitoring Colour Usage in Italian Municipal Web Interfaces

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ABSTRACT

We present a national, measurement-based characterisation of header background colours in Italian municipal websites. Using a corpus of 7,896 municipalities built by aligning ISTAT and IPA registries and by linking beneficiaries of PNRR Measure 1.4.1, we audited homepages with a headless browser to capture the computed background colours of the two header sections (centre and slim). Colours were retained as exact hexadecimal values for reference checks and counts, and were also converted from sRGB to CIE L*a*b*. Within-site differences between the two headers were quantified using the CIEDE2000 metric (ΔE_{00}). We report distributions of header colour categories, regional patterns in header palettes, the exact header hex values and the share of the institutional Blu Italia (#0066cc) in headers. Findings show that the blue family dominates nationwide, the exact reference #0066cc is comparatively rare, centre and slim headers usually match, and funding status is associated with higher measurability. The study is descriptive and exploratory and provides a documented snapshot together with a compact set of transparent measures that future research can reuse, extend and integrate into broader studies.

KEYWORDS Web standardisation; Italian municipalities; chromatic identity; municipal headers; Bootstrap Italia; PNRR 1.4.1; institutional blue (Blu Italia)

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1. Introduction

Public-sector websites are a primary interface between institutions and citizens. Within this interface, headers provide a sense of identity and support global navigation, typically including search functions and utility elements. Building on evidence that website colour appeal predicts perceived trust and satisfaction, including cross-cultural effects (Cyr, Head and Larios, 2010), and on psychological findings that link colour to affect and preference (Palmer and Schloss, 2010), we treat header colour as a measurable design signal at national scale. Although technical implementations and structural layouts may vary across websites, headers generally follow a relatively consistent design model and act as a visual point of reference for users, reinforcing the perception of the site as a coherent and unified entity (Lynch and Horton, 2009).

In Italy, the visual and functional design of municipal websites has been increasingly standardised through Designers Italia [1], a government initiative led by the Department for Digital Transformation and AgID (Agenzia per l'Italia Digitale). Launched in 2015, the initiative progressively steered public administration websites toward common design guidelines and accessibility practices, later consolidating into a mature design system and operational resources for administrations. Today, Designers Italia provides model websites for municipalities, documentation, and an official front-end (Bootstrap Italia [2]) to implement the design guidelines in practice. An official desktop model-evaluation app [3] exists for conformity checks on municipal sites; our study does not use its outputs and remains a descriptive colour characterisation. Within this framework, the institutional *Blu Italia* (hex #0066cc) was introduced to provide a representative and cohesive visual style for public-administration websites. The cultural lineage of blue in Italy predates digital guidelines: during the Renaissance, ultramarine from lapis lazuli elevated blue to a prestigious pigment, frequently associated with sacred iconography (Falcinelli, 2017). Its institutional adoption is also linked to the *azzurro* worn by Italian teams for sport competitions since 1911, a choice historically tied to the House of Savoy and to the “Blu Savoia”, which became a national symbol (Benelli, 2015; Acri, 2024). In contemporary digital contexts, predominantly blue interfaces have been reported to engage neural patterns associated with pleasant aesthetic processing (Nissen, 2020). Taken together, these strands motivate the use of *Blu Italia* as a reference point for assessing chromatic alignment in municipal headers.

Against this policy background, we assemble a country-wide corpus of 7,896 municipalities by integrating official registries from ISTAT [4] and IPA [5], reconciling identifiers

and normalising institutional URLs. We then link this corpus to open data from PNRR Measure 1.4.1 (Citizen Experience in Public Services) [6] to identify financed municipalities. In this study, header colour serves as a tractable proxy for institutional identity to assess convergence toward the institutional *Blu Italia* and to characterise chromatic patterns across regions and administrative contexts.

The aim of this study is to quantify, at national scale, the chromatic identity of Italian municipal website headers and their alignment with the institutional *Blu Italia* (#0066cc). We focus on colours as rendered by the browser and on the internal coherence between the centre and slim header bands, relating measurability to funding under PNRR Measure 1.4.1. The scope is descriptive: we characterise distributions, regional patterns and header-to-header differences (ΔE_{00}) without assessing usability, accessibility, or full model compliance.

While national guidance has encouraged convergence toward a shared visual language, most notably through the institutional *Blu Italia*, implementation across municipalities remains heterogeneous. In practice, components can be renamed or partially embedded; legacy templates persist, and the presence of Bootstrap Italia does not necessarily entail structural adherence to the municipal model. This gap between the intended standard and the realised interface motivates our enquiry and frames the scope of this paper: a nationwide, policy-aware descriptive characterisation of municipal header colours grounded in official registries and open data, together with interpretable summaries (choropleth maps, regional compositions, and hue distributions) that render large-scale patterns legible and useful for oversight of model adoption.

Our contribution is twofold:

- 1) We provide a national-scale, policy-aware characterisation of municipal header colours grounded in official registries (ISTAT, IPA) and the open datasets released under PA Digitale 2026. To our knowledge, this is the first measurement-based overview of the colours actually rendered in municipal headers and their relation to the institutional colour scheme promoted by Designers Italia.
- 2) We present interpretable summaries, including choropleth maps, regional compositions and hue distributions, which make large-scale patterns legible without presupposing specialist knowledge.

The remainder of the paper proceeds as follows. We first situate the study within Italian public-sector design

standards and the policy programme behind Designers Italia and Bootstrap Italia, together with the open-data context of PNRR Measure 1.4.1, to clarify the operational setting in which municipal websites are developed. We then present a nationwide characterisation built from official registries (ISTAT and IPA) linked to PNRR open data, reporting the distribution of header colours, the prevalence of the institutional blue, regional regularities and divergences, and the consistency between slim and center header sections.

Although blue emerges as the prevailing family at national scale, we also observe visible heterogeneity across municipalities, including provincial capitals. In several capitals the header background is green, red or white rather than blue, while others remain blue; this variety does not change the aggregate dominance of blue reported in our results. For clarity, throughout the paper “colour” refers to the computed background of the two header bands as rendered by the browser, not to hero images or other content that may influence the overall page impression.

2. Methodology

The unit of analysis is the municipality. We assembled a national corpus of 7,896 records by aligning the official statistical register (Elenco dei comuni italiani) [7] with the national administrative index (“Enti”) [8], restricting the latter to entities classified as municipalities. The two registers were merged using the **ISTAT municipal code** as the unique key and a left join, so that every municipality in the statistical register remains in scope even if no matching record is present in the administrative index. All data processing, web automation and analyses were implemented in Python (3.12.2): headless browsing with Selenium WebDriver [9], HTTP resolution and HTML parsing of computed styles, CIE L*a*b* conversions and CIEDE2000 calculations, geospatial joins for mapping, and figure generation.

2.1. Institutional websites

Institutional website addresses drawn from the administrative index were processed in two stages. First, an automated pass parsed each entry as a web address and normalised it to an HTTPS base URL, retaining only the scheme and host and discarding paths and query strings. During this step the parser also flagged obvious anomalies such as email strings, raw IP addresses, or generic provider placeholders that point to a platform rather than to a municipal hostname. Second, a manual review corrected only those flagged cases for which a reliable institutional domain could be verified. In practice, provider placeholders (e.g., halleyweb.com) were

replaced with the corresponding municipal host when identifiable; emails (e.g., anagrafesquillace@libero.it, serra.segreteria@gmail.com) and raw IPs (e.g., 62.77.55.13) were replaced with the municipality’s official domain. After curation, each municipality was associated with a single institutional website URL. This yielded a single institutional base URL for each municipality, totalling 7,896 municipalities (ISTAT; as of 30 June 2025).

2.2. Association between funding and colour availability

We merged the municipal list from §2.1 with the beneficiary lists of Measure 1.4.1– Citizen Experience in Public Services [10] to mark each municipality as financed or not financed. The merge used the IPA institutional code shared by both sources and ran automatically under the same rules for all records. Because the beneficiary lists were compiled before January 2024, we aligned them to the current municipal map [11] (for example, Alano di Piave, listed as funded in September 2022, was suppressed on 22 January 2024 to form Quero Vas; Moransengo was mapped to Moransengo-Tonengo, created on 1 January 2023). We then removed exact duplicates where the same municipality and the same CUP code [12] appeared in more than one row, keeping only a single entry for that municipality CUP pair. After these steps, 6,593 municipalities are marked as financed, corresponding to 83.5% of the national corpus. The financed label is descriptive and does not by itself demonstrate structural adherence to the municipal website model.

2.3. HTML audit and header colour capture

Starting from the consolidated municipal list, each homepage was loaded in a headless browser via Selenium WebDriver. A headless browser is just a browser with no visible window. It still follows redirects, runs JavaScript, and applies CSS, but code controls it, so we can repeat the same steps on thousands of sites. [13]. Redirects were followed to the terminal URL, which we logged together with the final HTTP status. Reachability was assessed only at the terminal URL and required HTTP 200. Use of the national municipal template based on Bootstrap Italia was assessed by scanning the HTML and the loaded stylesheets for unambiguous identifiers unique to Bootstrap Italia. A site was marked “Bootstrap Italia present” only if at least one of the following was found: the literal string bootstrap-italia in markup or CSS, or the CSS custom property --bootstrap-italia-version in a loaded stylesheet. This check indicates practical adoption of the design system and does not certify full structural conformity. As illustrated in the template screenshot (Figure 1a), the two header bands are visually distinct and correspond to the slim and centre headers.

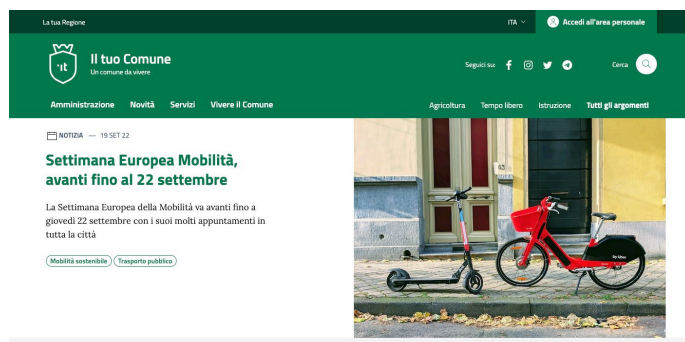


Fig. 1a - Example of a municipal website template (<https://comuni.designers.italia.it>)

For colour capture, we targeted the two canonical containers of the Designers Italia municipal model, `.it-header-slim-wrapper` and `.it-header-center-wrapper` (see Fig. 1b).



Fig. 1b- Header bands highlighted (slim and center).

We chose these selectors because they uniquely map to the slim and centre header [14] bands and are stable across releases. After the page and stylesheets had loaded, the script read each container's computed background-color. This returns the value after the CSS cascade, with variables, theme rules and overrides resolved at page load. We did not sample pixels or screenshots. If a header section was absent or its value could not be parsed, we recorded "No color information". According to the Bootstrap Italia documentation on custom colours, the primary palette for municipalities is rooted in Blu Italia (#0066cc) and white; Blu Italia is explicitly described as the identifying colour of the brand identity and the root for the primary palette [2]. Other hues (e.g., green) exist as theme variants for specific templates, so our measurement reports the colours actually rendered on live sites, capturing both strict adherence to the institutional primary and the presence of alternative theme choices.

For colour analyses, we included only municipalities with a terminal HTTP 200 and computable RGB values in both the slim and centre headers. The Bootstrap Italia flag was recorded descriptively and not used as an inclusion criterion.

2.3.1. Coverage and capture rates

Sites were considered reachable when, after redirects, the terminal URL returned HTTP 200 (OK); capture was

recorded when the computed CSS background colour was obtained for both headers. Requests were subject to time limits: HTTP requests had a 10 s timeout (also applied to linked stylesheets), the headless browser used a 20 s page-load and script timeout with an additional 3 s wait for the body element, and we inserted a 50 ms pause between records to avoid saturating hosts. The sample comprises **7,896** municipalities (**6,593** financed; **1,303** not financed). Overall, **89.3%** were reachable and **73.0%** had both header colours captured. Among financed municipalities ($n = 6,593$), **90.9%** were reachable and **84.2%** had a captured header colour (5,551/6,593). Among not financed municipalities ($n = 1,303$), **81.0%** were reachable and **16.6%** had a captured header colour (216/1,303). When reachability fails, the crawler typically encounters timeouts, DNS resolution problems, TLS/SSL handshake errors, connection resets, or automated blocking at the edge; in a small minority of cases the server returns explicit client/server errors (4xx/5xx).

2.3.2. Statistical association between funding status and colour availability

We tested whether funding status (financed vs not financed) was independent of having a captured header colour (computable in at least one header section) using a chi-square test; we report Cramér's V as the effect size (Cramér, 1946).

2.4. Colour parsing and categorisation

Achromatic tones were identified in the CIE $L^*a^*b^*$ colour space near the neutral axis of the ab plane (about 10 units around the origin) and split by lightness: Black ($L^* < 10$), Gray (10–90), and White (> 90). All remaining colours were assigned to one of eight chromatic groups by their angular position in the ab plane, with the hue angle H° obtained from the arctangent of a^* and b^* . Fixed ranges were Pink (0° – 27°), Red (27° – 45°), Orange (45° – 58°), Brown (58° – 78°), Yellow (78° – 90°), Green (90° – 200°), Blue (200° – 320°), and Violet (320° – 360°). In addition to these categories, the original colour values were retained to enable case-specific checks of institutional choices, notably the reference Blu Italia (#0066cc) and pure white (#ffffff).

Since each municipal header comprises two adjacent sections (center and slim), we assessed their internal coherence by computing the CIEDE2000 perceptual distance (ΔE_{00}) between the two backgrounds for each municipality. Distances were grouped into four interpretive buckets: Same (≤ 2), Close (2–10), Different (10–30), and Contrasted (≥ 30). Visual evidence is presented as categorical distributions of header colours: a national two-bar stacked chart reports, for each section, the share of municipalities in each canonical colour class. Figures depict categories, not exact colour codes.

2.4.1. Conversion and white point

We loaded each homepage in a headless browser and read the computed CSS background-color of the two header wrappers via `window.getComputedStyle`, which serialises channels as `rgb` (`r`, `g`, `b`) with integer values in 0–255; we therefore treated colours as 8-bit sRGB. For distance analyses (ΔE_{00}), these sRGB values were scaled to [0,1] and converted to CIE $L^*a^*b^*$ (D65 white) using `scikit-image rgb2lab` [15], without chromatic adaptation. For the maps (Fig. 6 and Fig. 7), we converted each RGB value to a six-digit hex code in lowercase (`#rrggbb`) and considered two colours equal only if the hex codes were identical; the Bootstrap Italia blue was counted only when the code was exactly `#0066cc`.

2.5. Geographic layers and mapping

For cartographic views, municipalities were linked to ISTAT's official administrative boundaries [16] for statistical purposes, updated to 1 January 2025. The join used the ISTAT municipal code; regional aggregates follow the same 2025 series. All maps in the Results use the same set of 7,896 municipalities defined in §2.1, after the updates and reconciliations described there.

2.6. Visual analytics and outputs

From the consolidated dataset we aggregated header colours into the canonical categories (§2.4) and computed category shares (municipality weight = 1). We visualise (i) the national composition with two 100% stacked bars (CENTER and SLIM) and (ii) territorial patterns with a region×category heatmap plus a single choropleth for the reference colour (Blu Italia, `#0066cc`) and a choropleth of the most-common exact HEX per region. Internal consistency between headers is analysed via the distribution of ΔE_{00} buckets (Same/Close/Different/Contrasted) and reported in the text without a dedicated graphic. Diagnostic plots (a^*-b^* scatter and hue histograms) are shown in the Results as supporting evidence.

2.7. Data quality, limitations, and mitigations

The upstream open-data sources required non-trivial cleaning and exhibit inconsistencies typical of administrative datasets (as already noted in §§2.1–2.2): outdated hostnames, provider placeholders, email addresses in URL fields, raw IPs, suppressed/merged municipalities, and duplicate CUP entries. On the web side, some homepages were unreachable or served incomplete assets; a minority applied overrides that temporarily hid template sections.

We mitigated data issues with automated normalisation and anomaly detection, light manual review of flagged rows, deduplication of municipality–CUP pairs, and by

reading computed styles after assets loaded to capture the effective theme. Unless stated otherwise, colour comparisons (e.g., ΔE_{00}) use the subset with a captured colour in both headers (BOTH: 5,765 of 7,896; 73.0%). For “has a colour” tallies we also report BOTH by default; using the “at least one header” definition (ANY: 5,767; 73.0%) adds only two rows and does not change one-decimal percentages. The two financed discordant cases are: (i) Ravenna, centre only (slim header absent); (ii) Fondi, slim only (the centre header element is not present in the HTML, e.g., `.it-header-center`).

3. Results

To test whether PNRR 1.4.1 funding is associated with the presence of a computable header color, we constructed a 2 × 2 contingency table (Table 1). A municipality is counted as captured when at least one of the two header sections (centre or slim) has a computable colour value.

	Captured	Not Captured	Total
Financed	5,551	1,042	6,593
Not Financed	216	1,087	1,303
Total	5,767	2,129	7,896

Table 1 Association between PNRR 1.4.1 funding and header colour capture (N = 7,896)

From these counts, the capture rates is **84.2%** for financed municipalities ($5,551 \div 6,593$) and **16.6%** for non-financed ($216 \div 1,303$). The association was tested with the Pearson chi-square statistic:

$$\chi^2 = \sum \frac{(O - E)^2}{E}$$

where O are the observed frequencies and E the expected frequencies under independence.

For this table, the result was:

$$\chi^2(1) = 2526.0, p < 0.001$$

Effect size was estimated with Cramér's V:

$$V = \sqrt{\frac{\chi^2}{n(k-1)}}$$

with $n = 7,896$ and $k = 2$, giving $V = 0.566$.

Funded implementations more often expose standard templates and stable CSS, making colours retrievable. Among non-funded municipalities this condition is uncommon and uneven. Overall, support under PNRR Measure 1.4.1 aligns with tangible adoption of the Designers Italia model and improved measurability.

3.1. Colour-space diagnostics (CIE Lab*)

Projecting validated centre-header colours onto the CIE $L^*a^*b^*$ a–b plane (Fig. 2) yields a broad arc with b^* below

zero and a^* around zero to mildly positive, indicating a dominance of blues/teals. A smaller cluster at high positive a^* and moderately positive b^* corresponds to reds/red-oranges. Greens occupy negative a^* and positive b^* . A compact cloud near the origin reflects near-neutral whites/greys, and there are few points at high b^* with low $|a^*|$, confirming the scarcity of yellows.

Category shares for the centre header ($N = 5,766$) are: Blue 65.4%, Green 15.7%, Red 7.5%, White 7.2%; all other families are <3% each.

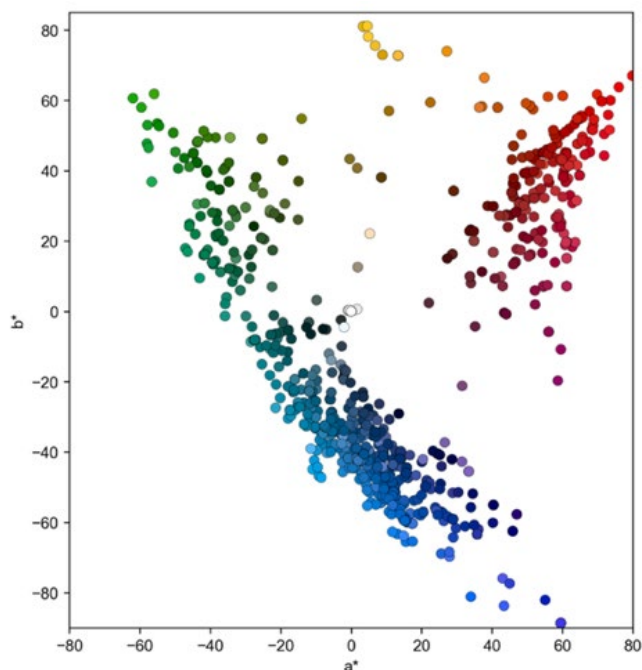


Fig. 2 - Centre-header colours in CIE Lab*. The a - b projection suffices to show the dominance of blues; a histogram is omitted.

The ab projection suffices to show the dominance of blues and the relative shares of greens and reds, so we omit the histogram.

3.2. National composition (Center vs Slim)

At national scale, **blue** dominates in both headers, followed by **green**; **red** ranks third and is comparatively minor. The notable difference lies in the neutrals: the slim header shows less white and more grey/black than the centre. Apart from this shift, the ranking by share is similar across the two headers, indicating a stable chromatic identity across components. Aside from the neutral shift, the family ranking by share is similar in the centre and slim headers. Minor families (pink, orange, yellow, violet, brown) are sporadic and do not materially affect the national picture. Complementing the national composition, we note visible heterogeneity across municipalities, including provincial capitals. Several inspected capitals display green, red or white header backgrounds, while

others remain blue; these cases show that blue is widespread rather than universal.

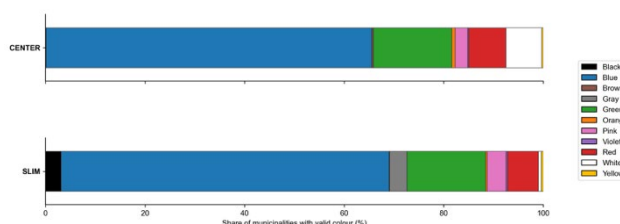


Fig. 3 - National composition of header colours by category for the centre and slim headers.

3.2.1. Colour difference between headers ($\Delta E00$)

To give a sense of scale, we show example colour pairs (slim above, centre below) taken from the median $\Delta E00$ in each band; these are illustrative only and do not define a canonical colour (Fig. 4). We quantify the per-municipality difference between the centre and slim headers with CIEDE2000 ($\Delta E00$) in CIE Lab*.

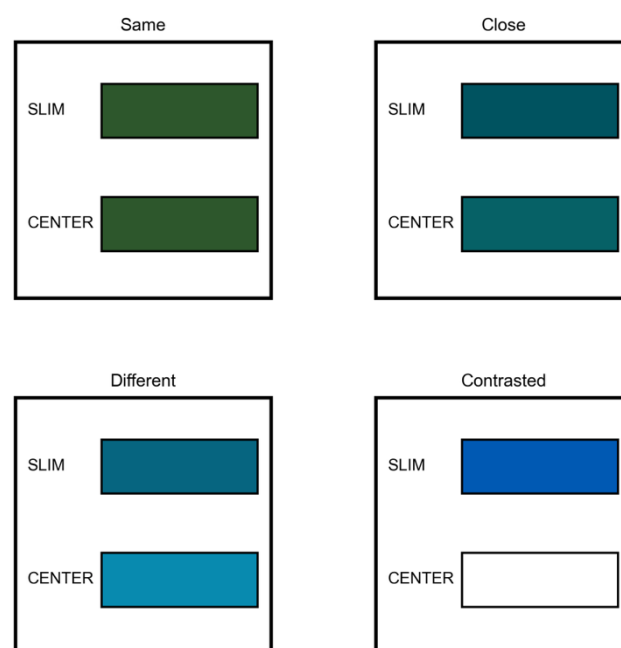


Fig. 4 - Examples of “Same”, “Close”, “Different” and “Contrasted” colour differences between the slim and centre headers.

The analysis includes all sites with both colours parsed ($N = 5,765$) and partitions $\Delta E00$ into four bands: Same (≤ 2), Close (2–10), Different (10–30), and Contrasted (≥ 30). Counts and shares are: **Same = 76 (1.3%)**, **Close = 2,845 (49.3%)**, **Different = 2,312 (40.1%)**, **Contrasted = 532 (9.2%)**. Thus, about half of the pairs (50.6%) fall in the Same/Close range; however, exact matches are rare (1.3%), so “consistency” is mostly close rather than identical. The remainder show a noticeable (40.1%) or strong (9.2%) change. The distribution centres around a

median $\Delta E_{00} \approx 9.96$, indicating a mild-to-moderate change overall.

3.3. Regional colour categories (heatmap)

Fig. 5 represents the heatmap of the abundance of each category of colour for each region. Blue is the main category nationwide. It peaks in Friuli Venezia Giulia ($\approx 75\%$) and is also high in Sicilia and Trentino Alto Adige, while Piemonte and Valle d'Aosta show the lowest blue shares. Green clusters in the South (Molise, Calabria, Sardegna). White is a visible secondary option in the centre-north (Emilia-Romagna, Toscana, Veneto). Red is limited to a few regions, especially Valle d'Aosta and Emilia-Romagna. Data availability varies: "No color information" is highest in Basilicata ($\approx 51\%$) and Piemonte, and low in Friuli-Venezia Giulia, Lombardia, and Sicilia. To complement the heatmap, the regional share of blue averages 47.2% with a standard deviation of 12.6% (range $24.6\text{--}75.3\%$).

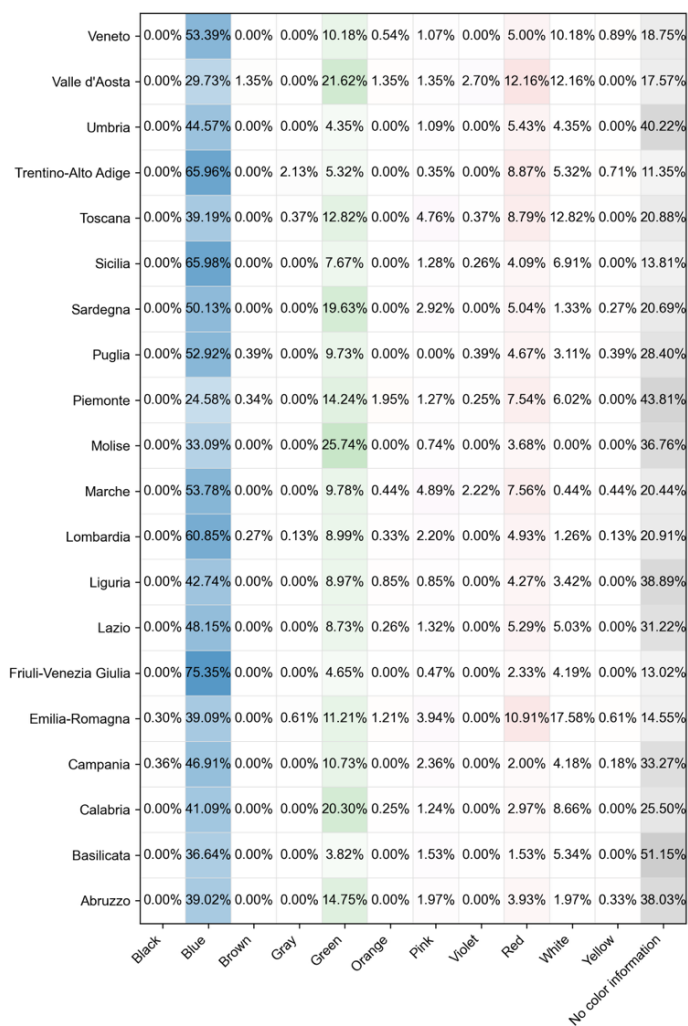


Fig. 5 - Region $\times$ category heatmap (it-header-center-wrapper). Percentages are calculated over all municipalities in each region. "No color information" is shown as a dedicated column.

3.4. Regional share of the most common exact header colour (HEX)

At the regional level, we report the share of municipalities that use the single exact HEX code (#rrggbb) that occurs most often as the header background in that region. A single code rarely dominates; in most regions the top code covers about 10–20% of municipalities. Clear concentrations occur in **Trentino-Alto Adige** ($\sim 56\%$, #003882) and **Friuli Venezia Giulia** ($\sim 54\%$, #003274), while Veneto is intermediate at $\sim 30\%$ (#003399). The **Bootstrap Italia primary blue** (#0066cc) appears chiefly in Lazio ($\sim 15\%$) and Sicilia ($\sim 10\%$). White (#ffffff) leads in Emilia-Romagna ($\sim 17\%$), Toscana ($\sim 13\%$), and Valle d'Aosta ($\sim 12\%$), and green (#007a52) in Molise ($\sim 26\%$), Calabria ($\sim 17\%$), and Sardegna ($\sim 13\%$). Overall, **dark blues prevail** among regional leaders, and convergence on a single exact HEX is uncommon.

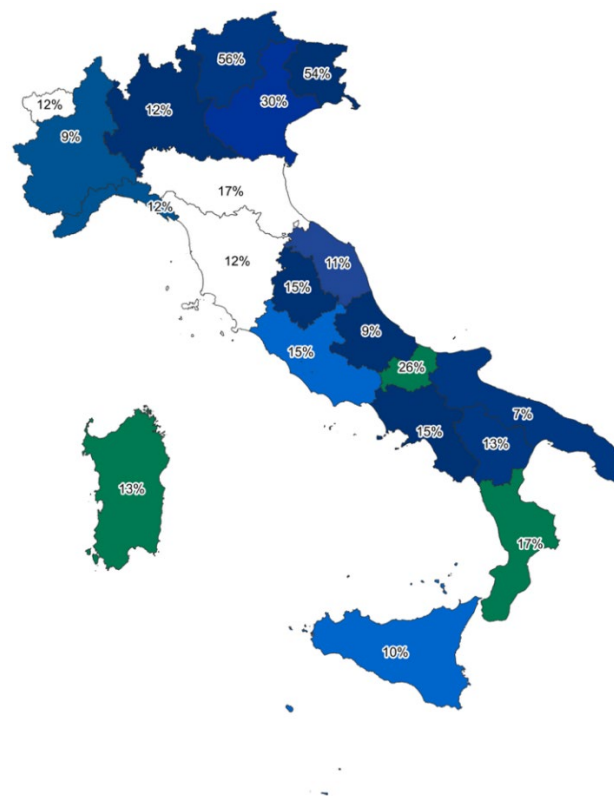


Fig. 6 - Most common exact header colour (HEX) by region - it-header-center-wrapper

3.5. Share of municipalities using Blu Italia (#0066cc)

In Fig. 7, Italian regions are visualized as a heatmap, with colour intensity reflecting the relative frequency of municipalities adopting Blu Italia in their slim website headers. As it can be seen, the use of the exact guideline colour is limited. Most regions lie between 0 and 10 percent, with the highest shares in Sicilia $\sim 10\%$ and Lazio $\sim 10\%$. Next are Sardegna $\sim 8\%$, Campania $\sim 6\%$, Marche $\sim 6\%$, Basilicata $\sim 6\%$, Puglia $\sim 5\%$, and Calabria $\sim 4\%$;

northern regions are mostly 0 to 3 percent. This pattern aligns with the regional map of exact HEX leaders, where #0066cc is the most frequent exact header colour only in Lazio and Sicilia.

Friuli–Venezia Giulia is informative: #0066cc is 0% in the center header, the blue category in the heatmap is 75.3%, and the most common exact colour is the darker #003274 at about 54%. This shows that blue is widespread as a category, while convergence on the precise #0066cc remains rare.

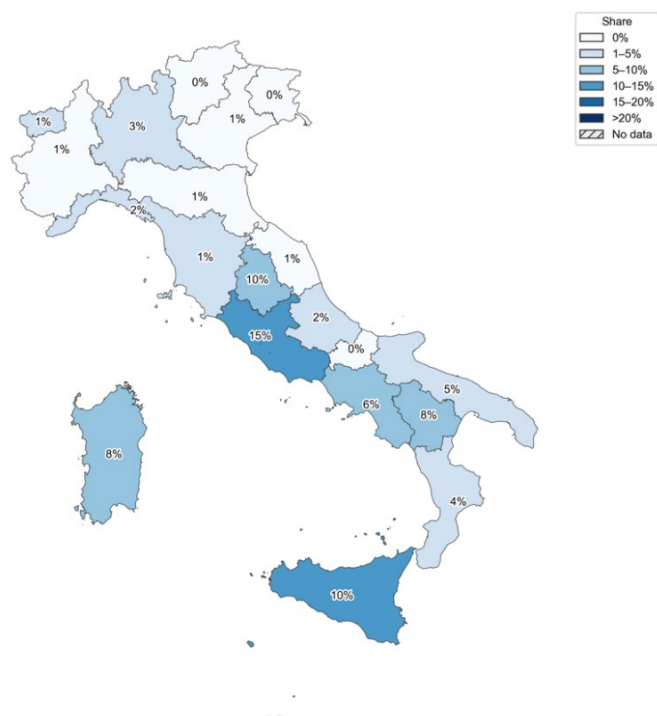


Fig. 7 - Share of municipalities using Blu Italia (#0066cc) by region – it-header-center-wrapper

4. Discussion

At national scale, municipal headers converge on the blue family. The exact institutional blue #0066cc is uncommon, while darker blues are often the predominant choices within regions. This points to alignment at the hue-family level rather than strict convergence on a single reference colour. Alongside the national prevalence of blue, our measurements also register a substantial share of non-blue headers; this observation is descriptive and does not alter the aggregate patterns reported above.

Within sites, the centre and slim bands are usually consistent: about half of pairs fall in the Same or Close ΔE_{00} range, the remainder show noticeable differences, and roughly one tenth is strongly contrasted. We refrain from functional interpretations and simply report these measured differences. Qualitatively, slim bands often appear darker; we note this without quantifying lightness.

Funding under PNRR 1.4.1 is associated with higher measurability. Financed municipalities more often expose stable, parsable front ends from which colours can be captured reliably. This is not evidence of formal compliance with the municipal model; it indicates that funded implementations are easier to audit.

From a policy perspective, the results can be read as lightweight indicators of progress. High measurability rates suggest that financed rebuilds expose stable front ends. The presence of Bootstrap Italia in markup signals practical adoption of the national model; the prevalence of blue in headers shows convergence at the chromatic level; and coherence between centre and slim bands reflects internal consistency. Together these indicators let municipalities benchmark against regional or national patterns and help agencies identify where additional support may be needed.

Standardisation turns a dispersed civic web into measurable public infrastructure, improving transparency and enabling lightweight, explainable indicators that non-specialists can read. Because many administrations now build with the same model, interfaces become comparable data; this regularity lowers the cost of oversight and lets researchers and civic groups build simple tools to track change. A few simple, reproducible measures are enough to track progress over time. At the same time, the visibility of actual municipal spending under PNRR Measure 1.4.1 for website rebuilds is uneven; references linking awards to procurement identifiers (CUP/CIG) are not systematically published and are often not machine-readable, constraining verification over time.

This study is descriptive and cross-sectional, based on alignment of ISTAT and IPA registries and linkage to PNRR 1.4.1 beneficiary lists. Results reflect the landing page at crawl time, so redirects, protection layers, cookie banners and late-loaded styles may affect computed colours. Detection of Bootstrap Italia relies on heuristic signals and should not be read as proof of formal compliance. The study does not assess usability, accessibility or normative conformity. Mitigations for data quality and measurement are reported in §2.7.

Future work should replace the single snapshot with periodic measurement so that trends are visible and simple to compare. A light extension to the method can add WCAG text–background contrast checks on header text and primary actions as a quick signal of alignment, by running a preliminarily scoped contrast screen limited to the two header bands (computed text colour vs. background) and reporting the share of sites meeting AA thresholds; this offers an initial compliance signal to trend over time without claiming a full accessibility assessment.

The goal is a simple, repeatable view of progress that anyone can read.

5. Conclusion

This paper establishes a national baseline for colour usage in Italian municipal website headers by linking official registries to PNRR 1.4.1 beneficiaries and capturing browser-rendered colours for both header bands. Municipalities align by family towards blue rather than on the exact institutional colour (Blu Italia). Within-site coherence between centre and slim bands is generally acceptable. Funding aligns with measurability, reflecting more stable and parsable structures without implying formal compliance.

The unusual degree of cross-municipal standardisation turns a diffuse web estate into a measurable public infrastructure. This unlocks transparency and continuous monitoring because simple colour-based indicators can be computed reliably, compared across regions and understood by non-specialists. Used alongside structural and accessibility checks, these indicators support longitudinal tracking and targeted support, and they enable researchers and civil society to build practical tools for oversight.

6. Conflict of interest declaration

The authors declare no conflict of interest.

7. Funding source declaration

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A review on Colour, Material and Finish Design: meaning, state of the art and research perspective

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ABSTRACT

This paper presents a literature review that investigates CMF (Colour, Material, Finish) design through academic research to understand its historical development and increasing importance in modern design theory. The current context demands aesthetic experiences that drive emotional engagement between consumers and products, thus making CMF design a strategic possibility. The multidisciplinary nature of this approach, which incorporates elements from psychology, materials science, ergonomics, and marketing, enables the design of meaningful product interactions and influences user perception. CMF design exists throughout professional practice but lacks sufficient academic research due to its complex nature, which creates fragmentation.

This research conducts a Systematic Literature Review (SLR) using the PRISMA framework to analyse 113 relevant sources. The results were displayed according to thematic categories, examining their history, definitional complexity, constituent elements, and design processes. Research demonstrates that CMF design is crucial for enhancing product identity, improving the user experience, and fostering sustainable engagement through a balanced combination of visual, functional, and emotional dimensions.

The research adds to academic knowledge about CMF design, demonstrating its ability to drive sustainable innovation. The aesthetic design of experiences through CMF fosters emotional bonds between users and products, leading to increased product durability and sustainable consumption patterns. Overall, CMF design lends itself well to integration with reflections on sustainability and as a possible driver in specific strategies for sustainable design.

KEYWORDS CMF design; Color; Material; Finishing; Design approach; Design process

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1. Introduction

Modern society has rapidly transformed consumption patterns, driven by technological advancements and market competition. In *'Rethinking Value in a Changing Landscape'*, Brand and Rocchi (2011) explored how social change reshapes values and perceptions, referencing

Toffler's (1980) concept of cultural 'waves' moving from the agricultural to the industrial and then the information age. Building on this, Gardien et al. (2014) identified four main paradigms: Industrial, Experience, Knowledge, and Transformation economies. Each reflects a stage in post-war development where the roles and values of designers, brands, and consumers evolve (see Table 1).

Industrial Economy				
Experience Economy				Transformation Economy
Knowledge Economy				
Value proposition	Pride of ownership (commodities)	Targeted experiences (brands)	Empowering creativity (platforms, open tools)	Ethical value exchange (trust, collaboration)
End-user benefit	Functional benefit	Attention for emotional, human needs	Sense of identity, self-actualisation	Attention for global and societal issues, ethical peace of mind
Cause of decline	Commoditisation, cheap competition, eroding margins	Brands fight for consumer's attention in crowded landscape, brands address market segments rather than individuals	Self-indulgence, rampant individualism, brand distrust, global networks cause fast dissemination of unethical practices	Possible cause: unequal sharing of extracted value between stakeholders
People Research objective	Fitting the product to the body and mind	Fitting the product to market segments, lifestyles and subcultures	Fitting the product to the individual's need for self-actualisation	Fitting the product not only to the individual but also to society and planet
People Research methods	Human factors, ergonomics, anthropometrics	Consumer psychology, ethnography, consumer confrontation testing	User-generated knowledge, expert knowledge and scientific models, monitoring behaviour	Empathic, in-context experimentation and data collection through living labs
Aesthetics	Functional, rational, universal, simple, pure, objective and absolutist	Diverse, eclectic, complex, ornamental, juxtaposed, subjective and marketing-led	User-generated, algorithmic, generative, aesthetics of interaction more important than aesthetics of appearance	Local executions based on parametric platforms
Innovative integration (process tools)	Rational problem-solving	Market segmentation, Personas, Scenarios, Experience flows	Rapid co-creation, open innovation, experience prototyping	Parametric platforms, visual/tangible storytelling, Cradle2Cradle sustainability
Brand	Communicates functional benefits	Communicates emotional benefits	Corporate brands move into the background, user become their own brands	Communicate transparently, instilling trust

Table 1: The four paradigms. Graphic elaboration by the author from Gardien et al., 2014.

Contemporary society is navigating the fourth paradigm — an era centred on ethical value exchange. According to Gardien et al. (2014), this shift is driven by growing discontent surrounding environmental and ethical concerns. As markets become increasingly saturated, functionality and performance remain essential, but aesthetic and experiential qualities are increasingly guiding consumer choice.

Within this landscape, Colour, Material, and Finish (CMF) design emerges as a crucial design approach. Although the acronym is recent, its principles have long been established in design practice and craftsmanship, where the interplay of colour, material, and finish determines the desired results (Kim, Lee and Suk, 2023). Today, CMF design extends far beyond visual and tactile selection, operating as an interdisciplinary field intersecting

psychology, design, materials science and manufacturing (Zuo, 2020). It addresses evolving sustainability demands and shifting consumer behaviour, enabling new dynamics in production such as mass customisation: 'the practice of creating products and services explicitly linked to individual customers' (Christoph and Piller, 2003). Modular CMF combinations allow customisation without excess stock or cost, offering viable solutions that empower consumer choice (Deserti and Qian, 2010).

CMF design also mediates aesthetic and experiential balance, responding to the demand for empathy in design through sensory engagement. While traditional design privileged the visual sense (Wang and Luo, 2016), designers now seek to activate all five senses (Chiu, Chen and Liao, 2020). Through multisensory perception, consumers generate knowledge and experience (Schifferstein and Desmet, 2008), forming emotional responses that shape perceived value (Becerra, 2016). Managing these emotions becomes a strategic opportunity for market positioning and differentiation (Kato, Botella-Carrubi, and Ribeiro-Navarrete, 2023).

Despite its growing importance, CMF design has received limited attention in academic research and literature. Research has examined material perception and its hedonistic dimension (Rognoli, 2004; Del Curto, Fiorani, and Passaro, 2010; Lerma, 2010; Camere and Karana, 2018; Veelaert, Moons and Du Bois, 2022), yet systematic studies on the reciprocal influences between CMF design, perceptual experience, and affordance remain scarce. Originating as a practice-based, industry-driven field, CMF lacks consistent terminology and scholarly lineage. Studies addressing colour, material, and finish individually or in their interaction (Del Curto et al., 2010; Rognoli, Salvia and Levi, 2011; Karana, 2012; Baxter, Aurisicchio, and Childs, 2015; Manu T. et al., 2022) rarely situate them within a CMF design framework, resulting in conceptual fragmentation.

As Zuo (2020) highlights, ambiguity persists in both the historical development and definition of CMF, which only entered academic discourse around 2005. Its interdisciplinary nature further complicates theoretical framing (Strappini et al., 2024). Positioned between disciplines yet fully belonging to none, CMF design suffers from theoretical vagueness and methodological dispersion. Moreover, much of its professional knowledge remains tacit or proprietary rather than publicly shared.

CMF also holds untapped potential for sustainability. As a vehicle for sensory and emotional meaning, it supports design for emotional durability and resource efficiency. By eliciting attachment, guiding use, and extending product lifespan, CMF can reduce obsolescence and encourage material consciousness.

This review is part of a broader investigation into the CMF design, sustainability, and behaviour change. It addresses the need for a systematic overview of CMF research to clarify its definitions, lexicon, and theoretical foundations. The central research question is: What is the current state of CMF design research in academia, and how can its insights contribute to more sustainable paradigms? In response to this gap, this review aims to consolidate the core concepts of CMF design by tracing its evolution, analysing current definitions, and highlighting its strategic role in contemporary practice. By bridging theory and practice, it seeks to articulate the design knowledge embedded in CMF approaches and outline directions for future research.

2. Materials and methods

2.1. Research method

The authors adopted a Systematic Literature Review (SLR) to shed light on the current academic and professional landscape regarding CMF design. As expressed by Zuo (2020), several researchers have studied and continue to investigate Colour, Materials, Finishes, and their interrelationships. However, including all studies that examine these elements individually would have led to an overly broad and heterogeneous dataset, inconsistent with this research. Therefore, to maintain focus and coherence, the authors set an initial boundary for their selection criteria, only including works in which CMF design is explicitly addressed as an integrated concept.

As noted by Lame (2019), the primary objective of the SLR approach is to minimise bias and enhance transparency at every stage of the review process. This is achieved through clearly defined, systematic methods for selecting and including studies, appraising their quality, and summarising them objectively (Liberati et al., 2009; Petticrew, 2001). Accordingly, the authors structured their analysis following the main steps of the PRISMA Statement (Nightingale, 2009), beginning with the definition of themes (Aguiar et al., 2022) that could shed light on the various aspects involved in investigating CMF design (Fig. 1).

The process involves several steps. First, the review questions are defined, followed by the inclusion and exclusion criteria (Lame, 2019). In this case, an initial identification phase enabled the establishment of which sources met the requirements (see paragraph 2.2). After removing duplicates, the sources were screened. Those selected and finally included were considered and admitted because they reflected and provided information on the defined topics through coding (Lame, 2019; Aguiar et al., 2022).

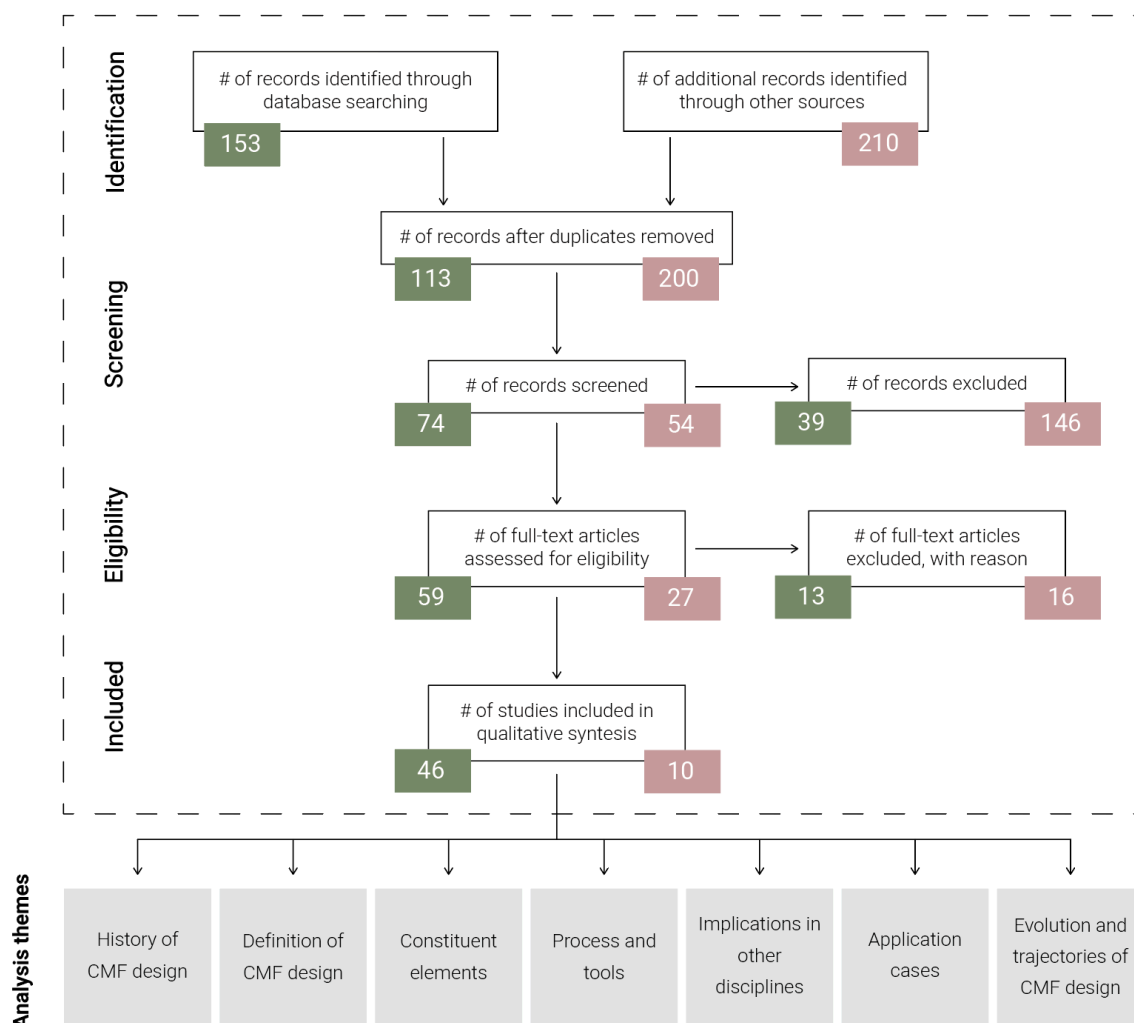


Figure 1: The steps of the Systematic Literature Review (Image by the author).

2.2. Data collection

The literature search was conducted using academic databases and engines such as Scopus, WoS, and Google Scholar, as well as the digital catalogue of Politecnico di Milano. The search queries used included: 'cmf AND design', 'cmf AND design AND surface', 'surface* AND design AND colour* AND material* AND finish*'. As mentioned above, one of the significant challenges in this process was the limited availability of literature on the subject, aside from the fact that the CMF acronym frequently appeared in unrelated contexts. Indeed, CMF stands for several unrelated terms, such as *Common-mode filter*, *compute-and-forward*, *common mode failure*, *composite metal foam*, *Crew Module Fairing*, *craniomaxillofacial*, and others, including names of chemicals and technical engineering concepts.

To ensure relevance, the first sorting was conducted by excluding publications written in languages not spoken by the authors — specifically, those not in English, Italian, or Spanish. Additionally, studies from fields unrelated to the

research focus, such as medicine, health professions, veterinary science, energy engineering, and physics, were discarded. Furthermore, articles that were inaccessible or unavailable were also excluded by default.

This initial process yielded 153 articles, which were then reduced to 113 after removing duplicates. The results confirmed the limited volume of scientific literature available directly related to CMF design. Given this scarcity and the practical, industry-driven nature of CMF, the authors extended their search to include a grey literature search. Using Google, they searched for relevant professional and industry-based sources using “*CMF design*” as a keyword. Ultimately, 27 sources were selected for inclusion in the analysis.

2.3. Data analysis

The 113 articles, identified in the literature, were systematically reviewed. The first stage involved reading the abstracts and eliminating the off-topic articles (74 articles were left). A second filtering followed, in which full texts were read, and additional articles were excluded for

lacking substantive relevance to the research objective (59 articles and 27 sources from the grey literature remained).

Once the core set of text was established, the authors proceeded to code the articles based on thematic relevance, grouping them into the following categories:

- History of CMF design
- Definition of CMF design
- Constituent elements
- Processes and tools
- Cross-disciplinary implications and systemic impacts
- Case applications
- Evolution and trajectories of CMF design (links with behaviour and sustainability)

For this initial framing review, which is intended to serve as a foundation for deeper investigation in future research, the analysis focused on the first four categories. These offer the clearest insights into the conceptual and operational dimensions of CMF design, while laying the groundwork for exploring its broader implications.

3. Results

3.1. History and State of the Art of CMF Design

The origin of the acronym CMF is often attributed to Italian designer Clino Trini Castelli, who is believed to have coined the term in the 1980s during the design of an office chair for Herman Miller (Bosoni, 2016). Another version credits Herman Miller itself, which opened its first CMF-focused showroom in 1996 (Xu, Wang and Xu, 2023). Regardless of its precise origin, the consumer goods boom of the 1970s and 1980s increased product complexity, making it necessary to separate and specify individual choices of colours, materials, and finishes (Perryman, 2021a).

CMF design gained professional prominence in the early 2000s. Companies such as Samsung Electronics, Motorola, and Nokia conducted early research into the integration of colour, material, and finish (Zuo, 2020). Nokia was among the first to align CMF design principles with consumer trends and technological developments (Perryman, 2021a), while Motorola established a dedicated CMF team in early 2006.

Before the term became widespread, CMF-related practices were already established in the automotive sector. The complexity of car interior design required the careful integration of colours, materials, and finishes to create balanced environments. Ford was among the first

to allow users to customise colours and finishes (Perryman, 2021a). The responsible department, known as Colour & Trim, has been replaced by CMF in many companies (Zuo, 2020). Thus, while CMF design principles predate the 1980s, they were not unified under a shared terminology and were often treated as part of colour design.

In academic and experimental contexts, developments in Italy differ from the wider international scene. In Italy, the 1970s marked a growing interest in multisensory design approaches involving colours, material perception, and the perceived object qualities. CMF design can be viewed as an evolution of expressive experimentation by designers such as Ettore Sottsass, Andrea Branzi and Clino Trini Castelli (Squatruto and Ferrara, 2023). Castelli introduced "Design Primario" (Castelli, 1999; Castelli and Petrillo, 1983), referring to the 'soft' characteristics of objects related to perceptual sensitivity — including colour, light, sound, smell, touch, and material finishing. This approach was featured in collaborations with institutions such as the Montefibre Design Centre and brands like ABET Laminates and Louis Vuitton (Bosoni, 2016).

Outside Italy, the term CMF was popularised in 2005 during the Berlin conference, *The Art of Plastic Design* (Xu, Wang and Xu, 2023; Zuo, 2020), where Tina Rippon presented the keynote 'Finish Trends - Getting the CMF (Colour, Material and Finish) Right' (Zuo, 2020). Earlier research into the interplay of colour, material and finish dates back to the 1980s in Japan, where Hiroki Aoki and Mai Suzuki explored the sensory properties of materials under different environmental conditions. Institutions including the University of Cambridge, the Royal College of Art, Kingston University, Delft University of Technology, and Politecnico di Milano also conducted related research without explicitly using the CMF acronym (Zuo, 2020). In 2016, Colombian designer Liliana Becerra (2016) published *The Fundamental Principles of CMF Design*, one of the first attempts to define CMF design outside academia.

Today, CMF is widely recognised in professional practice. Companies such as Volkswagen, Samsung, and Philips have established dedicated CMF teams (Liu and Kim, 2023), and specialised online platforms have emerged, including *Colour Material Design*, *The Colour Authority*, and *Colour of Saying*. Material libraries, such as *Material District* (Material District, no date) and *Material Connexion* (Material-minded Design | Material Connexion, no date), also provide CMF insights. Additionally, studios like Chris Lefteri Design conduct extensive research on CMF design trends (Chris Lefteri Design, no date).

Despite its widespread professional use, CMF remains underrepresented in academic research. Many scholars

do not explicitly use the term, complicating efforts to consolidate related studies. Its cross-disciplinary nature also challenges researchers working within rigid academic structures.

A notable exception is China, where CMF design has become a significant trend and the source of most related academic publications (Xu, Wang and Xu, 2023). The China Household Electrical Appliances Research Institute Innovation Design Centre has researched CMF design in electrical appliances (Zuo, 2020), while Covestro has collaborated with Tsinghua University on CMF design projects using recycled materials (Covestro AG, no date). In 2017, China launched the CMF Design Award to promote value and innovation (CMF Design Award, no date). The 2024 Design Shanghai exhibition, which hosted a CMF design and aesthetics conference, underscored the growing theoretical and aesthetic interest (Design Shanghai CMF conference schedule, no date). In Asia, CMF goes beyond practice to a deeper theoretical inquiry. Scholars such as Liu (2020) and Zhang (2020) have called for a greater understanding of CMF design, echoing Zuo's (2020) appeal for more scholarly attention. However, many of these studies remain accessible only in Chinese.

Finally, CMF design is slowly entering academia through dedicated programmes such as the Master in *Sensorial Surface Design* at POLI.Design, Italy; the *Colour, Material and Finish Design* online short course at Central Saint Martins, UK; the *Colour and Materials Design* MFA and MA at the College for Creative Studies in Detroit, US.

3.2. CMF Design definition

As with the ambiguity surrounding its origins and use, the definition of CMF design remains imprecise. As Zuo (2020) notes, there has never been a universally accepted definition of this term. Even among scholars, there is no consensus on the proper designation of the term, which is often used with different meanings within the same article, for example, as an *approach-strategy* (Kato, Botella-Carrubi and Ribeiro-Navarrete, 2023); *approach-discipline* (Valan and Paglierani, 2024), or a set of *methods-technology* (Wang and Wang, 2021).

CMF design has been described as a method (Xu, Wang and Xu, 2023; Liu, 2020), process (Zhang, 2020), design field (Gaetani, Brevi and Balloni, 2021), discipline (Salvoni, 2021; He and Zhang, 2023; Valan and Paglierani, 2024; Ugale, Bisoyi and Loudon, 2022; Ugale and Thakur, 2021; Becerra, 2016), theoretical framework (Kato, Botella-Carrubi and Ribeiro-Navarrete, 2023), meta-design approach (Squatrito and Ferrara, 2023), research direction (Liu and Kim, 2023), technology or set of methods (Wang and Wang, 2021) and more simply, as an approach (Zuo,

2020; Zuo and Peng, 2021; Kato, Botella-Carrubi and Ribeiro-Navarrete, 2023; Valan and Paglierani, 2024).

Among these interpretations, Zuo and Peng offer one of the few explicit definitions for both CMF and CMF design (Zuo and Peng, 2021):

- **CMF:** “the integration and optimisation of colour, materials, and processes (particularly the process of surface finishing) towards the most appropriate apparent form, function, and quality of the designed object” (Zuo, 2020).
- **CMF design:** “the identification of the solution for the colour, materials, and processes (particularly the process of surface finishing) for the designed object to balance aesthetics and function and offer the optimal user experience” (Zuo, 2020).

Although the authors do not explicitly define CMF design as a field or discipline, they consistently refer to it as an *approach*. The New Oxford American Dictionary defines “approach” as “a way of dealing with something”, and the Cambridge Dictionary as “a way of considering or doing something”. Accordingly, CMF design can be considered an *approach* — a way of doing design that focuses on colours, materials and finishes and on designing their relationship to enhance the product's attributes (Spence and Wan, 2015).

CMF design is integrated throughout the design process, from initial research to final production (Kato, Botella-Carrubi, and Ribeiro-Navarrete, 2023). It is primarily applied in product and interior design (Valan and Paglierani, 2024) across various industries, including furniture, apparel, cosmetics, home appliances, and automotive (Kato, Botella-Carrubi, and Ribeiro-Navarrete, 2023). At its core, CMF design concerns the interrelation between the product, the user, and the company.

For the product, defined by its colours, materials and finishes, CMF design shapes visual language and identity (Liu and Kim, 2023; Piselli et al., 2018), playing a key role in defining style (He and Zhang, 2023). Influencing elements that directly interact with the user it creates a strong visual and sensory impact (Liu and Kim, 2023). CMF design balances aesthetic and functional attributes (Zuo and Peng, 2021), achieving harmony between visual appeal and usability (He and Zhang, 2023; Salvoni, 2021; Ugale, Bisoyi and Loudon, 2022). By shaping aesthetic perception, it enhances the product's value and perceived quality (Zhang, 2020; He and Zhang, 2023; Kato, 2022b; Kato, Botella-Carrubi and Ribeiro-Navarrete, 2023), a key aspect of a good design (Kato, 2022a) that influences emotional engagement, brand loyalty, and product longevity, namely, the desire to take care of a product and

thus extending its life cycle (Kato, Botella-Carrubi and Ribeiro-Navarrete, 2023; Zhang 2020).

CMF design creates opportunity for meaningful experiences through innovative combinations of aesthetic and functional attributes (Kim, Lee and Suk, 2023). These experiences address users' emotional and unconscious needs (He and Zhang, 2023; Huang and Cui, 2021; Zhang, 2020), integrating design and psychology to meet product requirements (Zhang and Yuan, 2021). By aligning user needs with tailored aesthetic strategies, CMF design provides a specific and empathetic approach to product development.

From the company's perspective, effective CMF design strengthens brand differentiation (Zhang, 2020), thereby increasing product recognizability and competitiveness (Kato, Botella-Carrubi, and Ribeiro-Navarrete, 2023; Kato, 2022b; Liu and Kim, 2023; Huang and Cui, 2021). By conveying positive experiences and high quality, it enables consumer loyalty and reduces the risk of product failure. Through target analysis and style revision via minor adaptations, CMF design also allows companies to reach new consumers and enter emerging markets (Salvoni, 2021).

3.3. CMF elements: Colour, Material and Finishing

As previously discussed, colour, material and finish have been extensively studied across various fields. This section analyses each element individually in relation to its role within CMF design.

3.3.1. Colour

Colour is the first element perceived when interacting with an object and the most extensively studied of the three, particularly from a perceptual perspective, as it strongly influences cognition, emotion, and behaviour (Kato 2022a).

Artists and scientists have long explored the nature of colour. Technically, it is defined through hue, saturation, and lightness. Over the centuries, philosophers and researchers have developed systems to organise colours and their relationships (Boeri, 2010), including the works of Albert Henry Munsell, Lars Sivik, Anders Hard, and Shigenobu Kobayashi.

Designers must consider how light reflections affect colour perception (Kato, 2022b), as manufacturing processes and surface properties can alter appearance (Kato, 2022c). While technical accuracy and function are essential, the aesthetic, symbolic, and emotional value of colour remains central (Kato, Botella-Carrubi and Ribeiro-Navarrete, 2023).

Studies on colour psychology reveal how colours can evoke emotions and influence behaviour (Perryman, 2021b; Gupta and Sharma, 2018). Hemphill and Wexter investigated emotional responses to individual colours (Na and Suk, 2014), leading to models linking colours and emotional states (Liu, Zhao and Zuo, 2015). Darker

colours make forms appear slimmer than lighter tones, while neutral tones suggest calmness and austerity, and bright colours evoke liveness (Becerra, 2016).

Understanding both the semantics of individual colours and the effect of combinations is essential to communicate effectively with users (Salvoni, 2021). Colour perception and meaning vary widely across cultural contexts and personal experiences, influenced by factors such as environment, recognition ability, and background (He and Zhang, 2023). Thus, analysing audience and context is crucial in CMF design (Valan and Paglierani, 2024).

Given its emotional power and immediate impact, colour plays a key role in consumer choices and brand perception (Kato, 2022b; Kato, 2022c; Kato, Botella-Carrubi, and Ribeiro-Navarrete, 2023). Light and bright colours convey confidence, while white conveys honesty, red stimulates, darker colours convey luxury and elegance, blue represents ability, and black represents refinement, and brown communicates sturdiness (Kato, Botella-Carrubi, and Ribeiro-Navarrete, 2023). Understanding these psychological effects allows designers to shape brand values and consumer experience strategically. Colour is thus a fundamental element of CMF design to be deeply integrated with design thinking.

3.3.2. Material

Material is the essence of any object and the medium through which we experience the world. Its central role in human evolution is clear, with historical eras being named after materials: the Stone Age, the Copper Age, the Bronze Age and the Iron Age. Human progress has always been linked to material discoveries and technological advancement (Zhang and Yuan, 2021).

With advances in technology, materials have become crucial to design (Ashby and Johnson, 2003). Their exponential diversification has made selection increasingly complex: over 160,000 distinct materials have been identified in the past two decades (Papile, Del Curto and Coccia, 2021), contributing to what Manzini (1989) termed 'the hyperchoice'. Designers must therefore develop strong selection skills.

Digitalisation has led to online material libraries and tools that support this process (Del Curto and Dantas 2009; Ramalhete, Senos and Aguiar, 2010; Papile and Del Curto 2021). CMF design refines not only the choice of materials but also their combination within a product, bridging functional attributes (technical and performance aspects) with aesthetic ones (perceptual and emotional value) (Piselli et al., 2018).

Users initially assess whether an artefact meets physical and sensory requirements before considering style, cost, and broader social factors, such as sustainability (Zhang

and Yuan, 2021). The growing focus on sustainability has transformed material selection. Consumers increasingly seek ethical and ecological options; however, reliable data, such as Life Cycle Assessments (LCAs), are often missing, which enables greenwashing practices (Lefteri in Van Vliet, 2023). Designers must therefore link technical performance with transparent communication and user dialogue. Designers also elevate material value by embracing imperfections as desirable features. They must anticipate and meaningfully integrate potential changes due to light, heat or humidity (Ziarsolo, 2023).

CMF design gives materials a “voice”, as they not only realise products but also carry meaning. Through sensory interaction, materials evoke emotions and connect to unconscious desires (He and Zhang, 2023; Squatrito and Ferrara, 2023). Enhanced by colour and finish, CMF design can materialise sustainability and foster more responsible consumption.

Beyond physical essence, one expressive medium emerges: the surface.

3.3.3. *Finishing*

While colour and material have defined boundaries, finish acts as the *trait d'union* between them, both shaping and being shaped by each. Closely linked to sight and touch, it defines the initial interaction between the user and the product, and plays a central role in aesthetics (Morozzo Della Rocca and Zappia, 2022).

Finish acts on the product's ‘skin’ (Del Curto, Fiorani and Passaro, 2010), requiring specialised expertise, complex problem-solving, and processing time. Each material offers distinct finishing possibilities, producing varied tactile and visual effects. Technological advancements have expanded these options, enabling similar effects across various substrates (He and Zhang, 2023), thereby giving designers greater expressive freedom.

A carefully crafted finish enhances perceived quality and value (Niculescu et al., 2023), thereby enriching the consumer experience (Kato, Botella-Carrubi, and Ribeiro-Navarrete, 2023). It becomes a decisive factor in how a product is understood, used, and remembered.

3.4. *CMF design process*

As discussed, CMF design has yet to be systematised or standardised, resulting in varied and nuanced approaches. Its professional nature adds complexity, as most designers develop *ad hoc* processes rarely documented in academic literature.

Across different approaches, CMF design consistently combines rational and inspirational methods and tools (Zhang, 2020; Xu, Wang and Xu, 2023; Zuo and Peng, 2021). These range from quantitative techniques — such as perceptual testing, statistical user analysis, and measurement of physical colour, material, and texture

properties — to qualitative ones, including brainstorming, focus groups, and user profiling.

By analysing existing literature and professional communication channels, the authors have mapped the main CMF design stages (see Table 2). While their explanation varies depending on the designer's perspective, the process can generally be broken down into increasing levels of detail.

Most models identify three macro phases: analysis (exploration), operational (experimentation), and application (definition) (Valan and Paglierani, 2024; Zuo and Peng, 2021). Within these, specific steps detail these methods and tools employed.

Laura Perryman (2021b) identifies five main steps:

1. Defining the problem or brief
2. Collecting information
3. Brainstorming and Analysing
4. Developing and creating
5. Presentation and feedback

These correspond to a research phase, where designers gain insights into consumers and trends, leading to a visual storyline and moodboard for presentation and design development.

Liliana Becerra (2016) offers a six-step model, also cited by Ugale, Bisoyi and Loudon (2022):

1. Information gathering: understanding consumers, their habits and preferences, identifying relevant colours, shapes, and materials for them, defining the brief to identify the main relevant information about the target audience, budget, and timeframe. It also involves analysing the market and competitors.
2. Narrative building: developing storytelling, the message to communicate with the audience. Designers may create personas, identify market trends, and use moodboards to visualise desired emotions and sensations.
3. CMF strategy: analysing user-product interaction to determine key functional and emotional attributes.
4. Component analysis: examining each product element from production to finishing perspectives.
5. CMF palette development: curating materials and colours to express the desired design direction.
6. CMF development: applying finishes, working with suppliers and overseeing production.

This six-step framework remains the most referenced, though other variations exist. Salvoni (2021), for instance, expands it into ten steps — brief, company and competitor analysis, target and trend analysis, moodboard, message definition, CMF palettes, colour scheme, and application — adding details to the earlier model.



Analysis phase <i>Explore</i>	Defining the problem or brief Collect information Brainstorm and Analyse	Information gathering Establish a narrative Creating a CMF strategy	Brief Company analysis Competitor analysis Target analysis Trend analysis
Operational phase <i>Experiment</i>	Develop and create	Understanding part break up Creating CMF palettes	Moodboard Definition of the message CMF palettes Colour scheme
Application phase <i>Define</i>	Presentation & Feedback	CMF Development	Application and colour variants

Table 2. The structure of the CMF process is not always the same. The diagram illustrates how the CMF process, in general, can be broken down into three main phases. However, within it, one can find different views on the more specific steps (Image by the author).

Additional activities may be integrated depending on the project, such as surveys (Ugale and Thakur, 2021), brainstorming sessions (Zuo and Peng, 2021), testing (Piselli et al., 2018; Huang and Cui, 2021; Zuo and Peng, 2021) or colour and tactile experiments (Zhang, 2020). Zuo and Peng (2021) also highlight the inclusion of Participatory Design, where collaboration with end users provides valuable insights for refining outcomes.

In the final phase, designers move from colour scheme definition to detailed CMF documentation, presented through renderings or prototypes (Zhang and Yuan, 2021; Mango Design, 2024).

The process described above represents the most comprehensive CMF design model. However, it remains flexible: as seen from Table 2, depending on project goals, some stages, such as colour analysis or material selection, may receive greater emphasis. Each CMF element encompasses a complex background of technical and experiential knowledge that shapes the overall design process.

Complementary research activities often support CMF design, including User Research, Market Research and Trend Research (Zhang, 2020; Huang and Cui, 2021; Yin and Krotova, 2023).

- User Research explores audience characteristics and behaviour and can evolve into dedicated consultancy projects (Becerra, 2016).

- Market Research analyses competitors' products, costs, usage, colours, and material strategies (Becerra, 2016).
- Trend Research tracks social evolution to anticipate design directions and scenarios, as well as emerging user desires (Piselli et al., 2018; Dragt, 2023; Yin and Krotova, 2023).

4. Conclusion

This review has explored the theoretical and practical foundations of CMF design, highlighting its growing relevance and largely unexploited potential within academic research. From its historical evolution to the analysis of its core components, CMF design emerges as a contemporary, adaptive, and strategic design approach. Its multidisciplinary nature makes it especially suited to today's complex challenges, where intersections between engineering, psychology, marketing, and sustainability generate innovative outcomes.

As discussed, CMF design offers a wide array of tools, dynamics and application steps adaptable to different contexts and needs. Each phase can be deepened to focus on specific aspects such as colour analysis, material research, or trend exploration. This flexibility positions CMF design as a key driver of innovation (Huang and Cui, 2021). Its impacts go beyond aesthetics: by intentionally designing colour, material, and finish, CMF design shapes perception, fosters emotional connections, and enhances user experience.

Studies have shown that emotions drive consumer decision-making and that 60% of these emotions are influenced by design (Na and Suk, 2014). CMF design, therefore, plays a crucial role in creating emotional bonds with consumers, becoming a strategic element for driving sales and enhancing customer satisfaction.

By integrating functional and aesthetic dimensions, CMF design also holds promise as a catalyst for more sustainable behaviour, from extending product lifespans to reducing waste. The material selection process is crucial to addressing environmental challenges. By enhancing the visual and tactile qualities of a product, CMF designers counter the perception that sustainable products are less appealing. Exploring textures, finishes, and culturally embedded materials opens opportunities to promote sustainability without compromising design quality or engagement.

Finally, CMF design can act as a medium for cultural storytelling and value communication. Integrating local materials, traditional techniques, or symbolic colour codes reinforces identity and community while promoting environmentally conscious behaviours aligned with users' cultural values. Taken together, these dimensions position CMF design as a strategic lever for developing meaningful, innovative, and responsible products. Moving forward, it will be essential to deepen both academic and practical exploration. As a bridge between functionality, aesthetics and sustainability, CMF design has the potential to transform how we conceive, design, produce and interact with everyday objects.

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The authors declare that there is no conflict of interest regarding the publication of this paper.

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Light and Color in Low-Arousal Design: a Review Towards Inclusive Sensory Environments for Neurodiversity

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ABSTRACT

The increasing attention to neurodivergent people in the built environment is exposing the limits of architectural models still calibrated on neurotypical assumptions. In many everyday settings, visual conditions are optimised for a presumed “average” user, with little consideration for how light and color can generate overload, discomfort, or avoidance for those with atypical sensory processing. This article asks how lighting and chromatic design can more effectively respond to diverse sensory profiles, and what it means to treat perceptual differences as a question of equity rather than exception. Drawing on work in neuroscience, environmental psychology, autism studies, and inclusive design, it reviews evidence on how visual environments shape arousal, attention, and participation for neurodivergent users. The paper then discusses low-arousal strategies, circadian-informed lighting concepts, and guideline frameworks such as WELL, highlighting recurring patterns such as reduced visual complexity, controlled luminance and reflections, stable and flicker-free systems, and layered user control over light and color. On this basis, it introduces perceptual justice as a way of understanding lighting design in terms of fair access to sensory conditions and to decision-making power over them, developed through participatory and co-design processes with neurodivergent communities. Light and color are thus framed not only as technical parameters, but as central levers in the ethical project of creating environments that are genuinely inclusive of perceptual diversity.

KEYWORDS Neurodiversity, Inclusive design, Light, Color, Perceptual justice, Low-arousal environments

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1. Introduction

In recent years, debates on inclusion have shifted from a narrow focus on physical access to a broader attention to cognitive and sensory differences. Instead of assuming a single, standard way of perceiving and processing the world, the neurodiversity perspective foregrounds multiple perceptual profiles, including those associated with autism, ADHD and sensory processing differences (Robertson and Baron-Cohen, 2017). This shift is reshaping how the built environment is discussed, framing spaces not only as containers of activity but as active mediators of how stimuli are organised, filtered or intensified (Mostafa, 2015). At the same time, many buildings and interiors still rely on standards that implicitly assume neurotypical users as the norm (Manning, Williams and MacLennan, 2023), so that visual conditions optimised for an “average” user can become sources of discomfort, confusion, or emotional strain for people with atypical sensory processing (Zaikina *et al.*, 2025). Light and color should therefore not be regarded as neutral background conditions, but as core perceptual variables shaping how spaces are perceived and lived (Hidayetoglu, Yildirim and Akalin, 2012). Key factors such as illuminance, flicker, spectral distribution, correlated color temperature, and surface reflectance influence visual comfort, arousal, and perceived control over the environment (Küller *et al.*, 2006; Boyce, 2010; Rossi, 2019b), with effects that become particularly marked among individuals who are hyper- or hyposensitive to visual stimuli (Yoshimoto *et al.*, 2020; Nair *et al.*, 2022).

Research in environmental psychology and neuroscience shows that poorly managed visual conditions, particularly when excessive or unstable, can impair attention, increase stress, and limit participation in everyday activities (Westland, Pan and Lee, 2017; Rossi, 2021; Nair *et al.*, 2022; Finnigan, 2024). This review builds on these findings to explore how sensory-aware, low-arousal design can inform more inclusive approaches to lighting and color in architecture, and introduces perceptual justice as a framework for analysing how sensory conditions and control are shared among users within prevailing design standards (Mostafa, 2015; Abdelmoula, Bouayed Abdelmoula and Abdelmoula, 2024).

It reframes discussions on neurodiversity and the built environment by focusing on light and color as primary drivers of arousal, perceptual organisation and everyday participation (Black *et al.*, 2022). This builds on reviews linking color and light to psychological functions and emotional responses, while extending their insights to neurodivergent sensory profiles and low-arousal design (Westland, Pan and Lee, 2017; Bortolotti *et al.*, 2022; Jonauskaitė and Mohr, 2025; Zaikina *et al.*, 2025).

Building on this, the article advances perceptual justice as a central interpretive and ethical lens to analyse how lighting and color conditions allocate sensory risks and opportunities for control, and it interrogates existing standards and guidelines by foregrounding their neurotypical assumptions instead of treating them as neutral technical references (Manning, Williams and MacLennan, 2023; Chidiac, Reda and Marjaba, 2024). In this way, the review connects empirical evidence, design practice and regulatory discourse, showing how light and color can be mobilised to promote more equitable sensory conditions for neurodivergent users (Higuera-Trujillo, Llinares and Macagno, 2021; Narenthiran, Torero and Woodrow, 2022).

This article is a narrative review that brings together evidence and concepts from neuroscience, environmental psychology, autism and neurodiversity studies, and lighting and color research and design. The literature was identified through database searches and citation chaining, prioritising peer-reviewed empirical studies, scoping or systematic reviews, post-occupancy evaluations, and standards or guideline documents explicitly addressing lighting, color and sensory accessibility. The focus is on visual environments in everyday educational, workplace, healthcare and public settings relevant to neurodivergent users. As a narrative review, it does not aim at exhaustive coverage and is limited by the predominance of studies conducted in Western contexts and by the uneven level of actionable detail available for design applications.

2. Neurodivergent Sensory Processing and Visual Environment

Neurodivergent individuals—such as those with autism, ADHD, or sensory processing differences—often perceive their surroundings in ways that differ from typical expectations. Rather than treating these differences as impairments, the neurodiversity perspective emphasises varied thresholds and responses to sensory input, including hypersensitivity or reduced responsivity to visual stimuli and difficulties in filtering irrelevant information. These patterns shape how environments are perceived, interpreted and navigated (Ben-Sasson *et al.*, 2008; Schauder and Bennetto, 2016; Robertson and Baron-Cohen, 2017). Clinical and design research indicates that visual environments can become significant sources of stress for people with atypical sensory processing (Kwon *et al.*, 2023; Tancredi and Abrahamson, 2024).

When visual input is overly complex—for example due to high contrast, crowded stimuli or abrupt changes in lighting—arousal levels may rise, interfering with

concentration and prompting avoidance strategies. In settings such as schools and offices, these conditions can turn formally accessible spaces into places that require substantial cognitive and emotional effort to use over time (Tola *et al.*, 2021; Liu, 2024).

Common design practices often rely on strong visual cues, repetitive patterns and dynamic surfaces, which can increase perceptual load, especially when users cannot anticipate or modulate sensory input (Mostafa, 2015; Nair *et al.*, 2022). For many neurodivergent individuals, having a visual field that remains relatively stable and can be adjusted when needed is crucial for feeling safe, managing emotional responses, and staying actively engaged in the space (Riordan *et al.*, 2024).

These insights suggest that sensory accessibility cannot be reduced to removing physical barriers alone, but requires careful calibration of intensity, organisation, and dynamics to align spatial conditions with diverse perceptual profiles (Leshkov *et al.*, 2024). This provides a basis for low-arousal approaches that explicitly address the relationship between neurodivergent sensory processing and spatial experience (Lukava, Morgado Ramirez and Barbareschi, 2022; Weber *et al.*, 2024).

3. Light and Color as Perceptual Variables in Sensory-Inclusive Design

Light and color jointly structure spatial experience, influencing perceptual organisation and affective responses. Luminous and chromatic configurations actively mediate sensory integration, with direct implications for arousal, comfort, and engagement (Hidayetoglu, Yildirim and Akalin, 2012). For neurodivergent users, whose sensory thresholds and modulation patterns may differ from neurotypical norms, these variables can significantly amplify or attenuate perceptual load (Mostafa, 2014; Black *et al.*, 2022).

3.1. Luminous parameters and visual discomfort

Research on lighting and environmental psychology identifies several luminous conditions that contribute to visual discomfort and sensory overload, including high luminance levels, strong discontinuities between task and background areas, glare (direct and reflected), and temporal instability of light.

Studies on temporal light modulation indicate that flicker, even when not consciously perceived, can induce visual fatigue, headaches, and a general sense of discomfort in visually sensitive individuals (Wilkins, Veitch and Lehman, 2010; Yoshimoto *et al.*, 2020; Miller *et al.*, 2023). In educational and therapeutic environments, unstable or

poorly diffused lighting has been associated with reduced engagement and increased avoidance behaviours among neurodivergent users, underscoring the role of luminous parameters in shaping perceptual comfort and arousal (Pence, Wagoner and St Peter, 2019; Nair *et al.*, 2022).

3.2. Color, materials, and visual complexity

Chromatic choices and material properties interact with light to determine overall visual complexity and stimulus salience. Experimental studies show that highly saturated colors, strong value contrasts and intricate patterns tend to increase arousal and perceptual load, whereas moderated contrasts and lower chromatic saturation are more often associated with calm, legibility and comfort (Gifford, 1988; Kaya and Epps, 2004; Hidayetoglu, Yildirim and Akalin, 2012).

These patterns are consistent with broader reviews that document robust links between color, emotional responses and psychological functioning across a range of environments (Westland, Pan and Lee, 2017; Bortolotti *et al.*, 2022; Jonauskaitė and Mohr, 2025).

Beyond chromatic attributes, visual complexity is shaped by how information is distributed in space.

From a visual neuroscience perspective, spatial organisation and frequency content are equally critical, as shown in work on receptive fields and spatial frequency coding in the primary visual cortex (Grzywacz, Watamaniuk and Mckee, 1995; Seriès, Lorenceau and Frégnac, 2003). Because the visual system is highly sensitive to edges and gradients, perceptual load depends not only on which colors are present, but on how contrasts and transitions are distributed across the field of view. Both overly simplified scenes, with low spatial frequency content, and highly cluttered, high-contrast patterns can increase visual strain, especially for individuals with atypical sensory processing (Wilkins, 2016; Yoshimoto *et al.*, 2020; Price, Sumner and Powell, 2025).

For low-arousal design, the objective is therefore not simply to minimise stimulation, but to calibrate the structure of visual information so that patterns, contrasts and chromatic transitions remain readable and sustainable over time.

In line with the literature on sensory-friendly design, Figure 1 illustrates a low-saturation Color palette contrasted with highly saturated Colors that tend to increase visual load.

In neurodivergent-inclusive contexts, visual complexity is not solely a function of color itself, but of how chromatic elements are organised within the spatial field and combined with textures, patterns, and surface reflectance.

Excessive visual density may compromise predictability and increase cognitive demand, particularly for users with difficulties in filtering or prioritising visual information

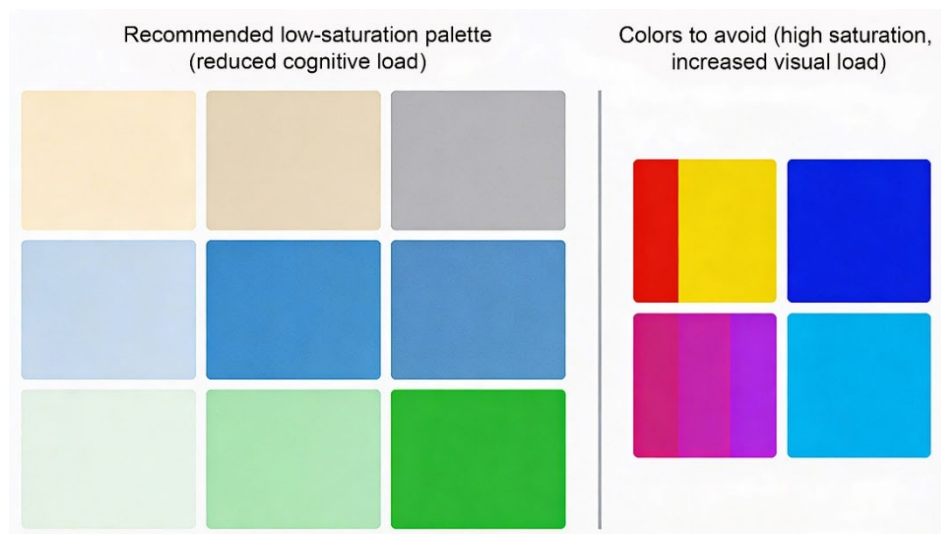


Fig.1. Low-arousal Color palette. Left: recommended low-saturation background Colors; right: highly saturated Colors that increase visual load and should be limited on large surfaces

In practical terms, this suggests avoiding both featureless, uniformly lit expanses and highly intricate, high-contrast motifs that saturate the visual field with edge information. Medium-scale patterns, graded surface transitions and moderated value and chroma contrasts can support perceptual legibility while limiting unnecessary arousal in visually sensitive users.

3.3. Light dynamics and user control

Changes in light levels and spectral content influence how a space feels, alertness, comfort, and overall atmosphere—particularly when changes occur suddenly or without clear rhythm. Studies show that perceived control over lighting can reduce discomfort and support sensory regulation (Houser and Esposito, 2021).

What emerges as especially important in this context are smooth transitions and the availability of adjustments that help ensure temporal consistency and predictability, both of which are essential in creating environments that support diverse sensory needs (Karyono *et al.*, 2020). Within this logic, light and color become adjustable variables that can be used to prevent peaks of sensory overload and support self-regulation strategies.

Taken together, luminous intensity, temporal stability, chromatic organisation and control options constitute core perceptual variables shaping sensory experience. Understanding how these variables interact provides the basis for design approaches that reduce sensory stress while supporting participation, framing low-arousal environments not as uniformly dim or neutral, but as configurations in which visual conditions are carefully calibrated to minimise overload and enhance perceptual legibility.

4. Design Guidelines and Low-Arousal Strategies for Neurodivergent-Inclusive Spaces

Low-arousal design originates in autism-related contexts, where sensory overload and difficulties in filtering stimuli are well documented.

More recent studies show that similar environmental stressors—such as excessive visual complexity, glare, flicker and unpredictable changes—also affect individuals with ADHD and sensory processing disorders, although reactions vary across profiles (Price, Sumner and Powell, 2025). Autism-specific frameworks like the Autism ASPECTSS™ Design Index (Mostafa, 2013) have been central in translating sensory concerns into explicit spatial criteria, focusing on domains such as acoustics, spatial flow, escape spaces and sensory zoning, all aimed at making environments more predictable and manageable (Mostafa, 2018). Post-occupancy evaluations of classrooms applying ASPECTSS™ principles report higher engagement and fewer avoidance behaviours when indirect, glare-free lighting and low-saturation color schemes are used consistently across learning and transition spaces (Black *et al.*, 2022).

Beyond autism-specific settings, sensory-friendly design literature highlights the value of reducing visual distractions, with recurring strategies such as controlling glare and flicker, softening contrast levels and limiting intense saturated colors (Felix, 2022; Watchorn *et al.*, 2025).

Experimental work in therapeutic rooms for neurodivergent children suggests that diffuse lighting, neutral to warm color temperatures, and simplified visual

palettes tend to lower physiological arousal and support longer voluntary engagement (Tola *et al.*, 2021). At the same time, evidence indicates that there is no single “ideal” sensory environment for all neurodivergent users; low-arousal design should therefore be understood as a flexible set of strategies aimed at reducing sensory stressors while supporting individual balance across different sensory profiles (Narenthiran, Torero and Woodrow, 2022).

Mainstream certification systems such as WELL v2 (IWBI, 2025) establish baseline requirements for illuminance, glare control, spectral quality and lighting controls to support visual comfort and circadian health (Figueiro *et al.*, 2019; Rossi, 2019a), yet they mostly reflect average responses and only partially address heightened sensitivities common in neurodivergent groups (Finnigan, 2024).

Studies of flexible offices and public interiors with user-adjustable lighting show that perceived control over illuminance and color temperature is associated with improved comfort and reduced reported sensory stress among neurodivergent adults, pointing to the value of layered systems rather than fixed “optimal” settings (Karyono *et al.*, 2020).

Across the reviewed literature, a set of recurrent operational principles emerges for translating low-arousal concepts into lighting and color strategies for neurodivergent-inclusive environments.

These principles do not prescribe fixed solutions, but identify conditions that consistently reduce sensory stress while supporting perceptual regulation and participation.

The main operational principles include:

1. Reducing visual load through organised layouts and calm background fields, limiting unnecessary visual stimuli and improving perceptual legibility (Harwell, 2025),
2. Controlling luminance and reflections by favouring indirect lighting strategies and matte surface finishes, to minimise glare and high-contrast visual discontinuities (Altenmüller-Lewis, 2017; Ghazali, Md Sakip and Samsuddin, 2019),
3. Moderating spectral composition and chromatic saturation, reserving high contrast and vivid colors primarily for functional cues and wayfinding (Zaikina *et al.*, 2025),
4. Ensuring temporal stability and flicker-free systems, as even imperceptible temporal modulation can contribute to visual fatigue and discomfort among visually sensitive users (Parmar *et al.*, 2021; Nair *et al.*, 2022).
5. Creating zones with differentiated sensory intensity, allowing users to move between areas with varying levels of visual stimulation and supporting individual self-regulation strategies (Abdelmoula, Bouayed Abdelmoula and Abdelmoula, 2024).

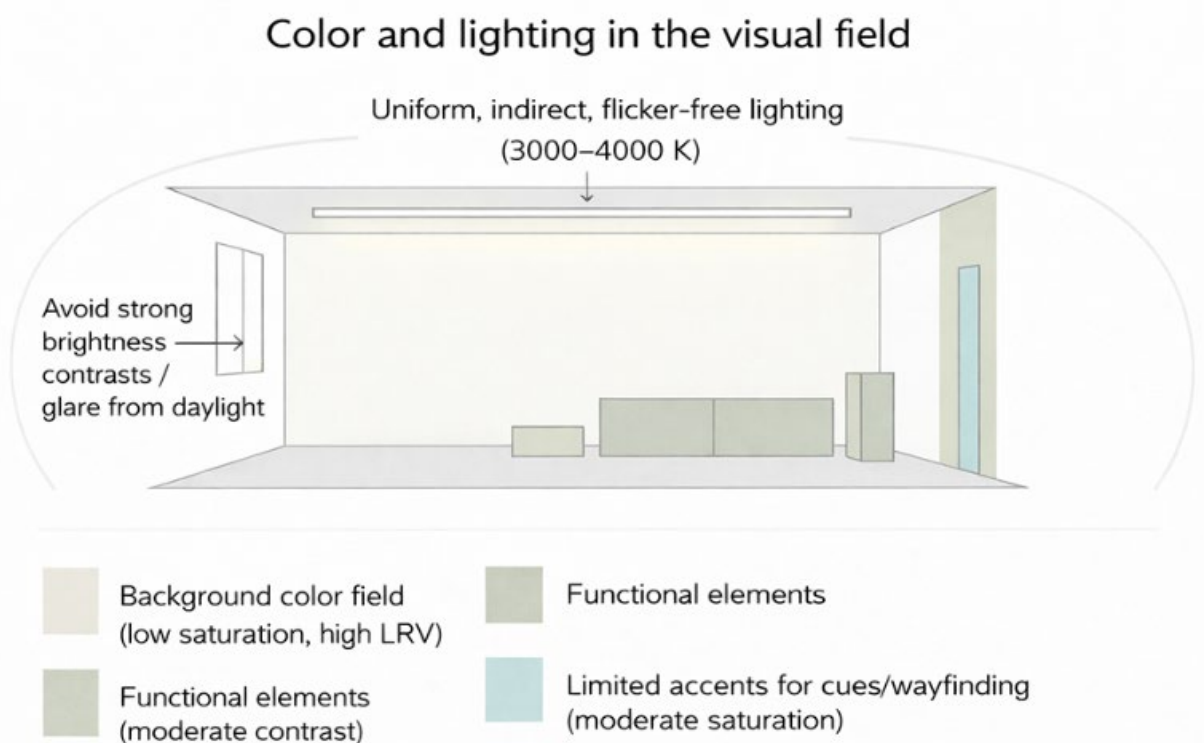


Fig. 2. Color and lighting in the visual field. Low-saturation backgrounds, limited accents, and uniform, indirect, flicker-free lighting support low-arousal conditions.

The effectiveness of these strategies depends on their integration within participatory design processes. Co-design (Binder, Brandt and Gregory, 2008; Sanders and Stappers, 2008) with neurodivergent users is essential to ensure that adjustable lighting and color systems are truly responsive to diverse sensory profiles (Black *et al.*, 2022; MacLennan *et al.*, 2023; Wohofsky *et al.*, 2023), preparing the ground for a broader discussion of perceptual justice in lighting and color design.

5. Towards Perceptual Justice: Framework and Design Implications

Perceptual justice offers a framework for examining lighting and color not only in terms of comfort or aesthetics, but in relation to how sensory conditions and degrees of control are differentially distributed among users. Environments designed around “average” standards may systematically privilege some sensory profiles over others, so that discomfort, disorientation or overload become forms of exclusion as concrete as physical barriers (Tola *et al.*, 2021). In this sense, lighting and color conditions operate as channels of both inclusion and exclusion in everyday spaces. From a regulatory perspective, a perceptual justice approach calls for moving beyond comfort standards based on an “average” user and explicitly recognising diverse sensory thresholds and the need for adjustable visual conditions. Building codes, guidelines and certification schemes should therefore include criteria that address not only illuminance, glare and spectral quality but also temporal stability, spatial complexity, predictability and the extent of user control over lighting and color settings. Framed in this way, light and color become tools for upholding sensory rights in the built environment, embedding perceptual equity within compliance processes rather than treating it as an optional goal (Houser and Esposito, 2021).

Research on neurodivergent experiences of the built environment consistently reports that lighting issues, excessive visual complexity and a lack of predictability can trigger distress at work, in education and in public settings, calling into question design and regulatory standards that prioritise typical visual responses (Narenthiran, Torero and Woodrow, 2022; Rattray *et al.*, 2026).

Neurodivergence, however, encompasses a wide range of sensitivities: what feels appropriate for one person may be overwhelming for another, which challenges any single notion of “normal” sensory conditions (Taylor, 2019).

A perceptual justice perspective therefore shifts attention from fixed norms towards environments that can adapt and respond to diverse needs, treating flexibility, gradation and control as core design requirements rather than optional

refinements (Finnigan, 2024). In practical terms, applying perceptual justice to lighting and color involves three main directions.

- **First**, recognising and minimising sensory risk factors—such as glare, flicker, harsh contrast and crowded visual fields—even when they fall within standard comfort metrics (Wilkins, Veitch and Lehman, 2010; Zaikina *et al.*, 2025).
- **Second**, implementing layered lighting and color systems that allow variations in brightness, distribution and spectrum across zones and activities, rather than relying on uniform “one-size-fits-all” settings (Mostafa, 2018; Chrysikou *et al.*, 2025).
- **Third**, integrating areas with consistently low-arousal conditions into layouts, offering spaces for retreat, regulation and quiet focus within otherwise more stimulating environments (Abdelmoula, Bouayed Abdelmoula and Abdelmoula, 2024).

Equally important is how these choices are made. Participatory and co-design methods ensure that decisions reflect lived experiences rather than assumptions.

Perceptual justice, in this sense, reframes inclusion not as mere access but as agency, placing users in active roles in shaping how their sensory environment works (Beck *et al.*, 2026).

Perceptual justice: design directions

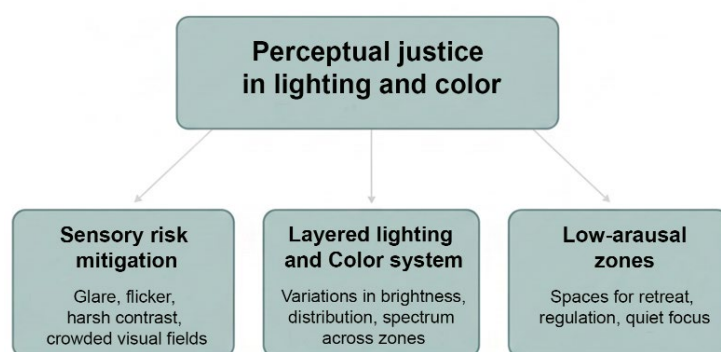


Fig.3. Perceptual justice in lighting and Color: three main design directions (sensory risk mitigation, layered systems, low-arousal zones)

By treating light and color as instruments of perceptual justice, they cease to be purely technical parameters and become part of the ethical evaluation of design choices, supporting a broader rethinking of standards and practices towards environments that are genuinely inclusive of perceptual diversity (Higuera-Trujillo, Llinares and Macagno, 2021; Chidiac, Reda and Marjaba, 2024).

6. Conclusions

This paper explored how light and color shape not just the appearance of space, but the way it is felt and lived, especially for people with different sensory needs. They actively influence perception, behavior, and inclusion. It has drawn on interdisciplinary research to show that visual conditions can either support or undermine people's ability to focus, feel safe, or participate in everyday environments. When not well managed, they risk creating invisible barriers that exclude neurodivergent individuals. A key contribution of this work is to frame perceptual justice as a lens that makes explicit who can feel at ease, regulate arousal and exercise meaningful control over lighting and color, shifting inclusive design from compliance with average comfort standards toward a more equitable distribution of sensory conditions and control.

From a practical standpoint, the findings underscore the importance of lighting and color systems that reduce unnecessary sensory stress while still offering clarity and usability, positioning flexibility and user agency as core values of sensory-inclusive design. More broadly, it calls for a shift in how inclusion is defined—not just as access to space, but as access to perception itself, making light and color central to evaluating how built environments accommodate perceptual diversity.

7. Conflict of interest declaration

The author of this piece of research declares no known conflict of interest with other people and/or organisations.

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Colour as Mediator: Perception, Materiality, and Technology in Contemporary Visual Culture

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ABSTRACT

This article develops a theoretical-critical synthesis of contemporary colour research by framing colour as a multifaceted object that operates simultaneously as a perceptual variable, a cultural code, a chromo-material strategy, and a technological-epistemic construct. Rather than offering a venue-specific review, the paper proposes an integrative framework that bridges design, heritage, digital systems, and sustainability. Four thematic axes are discussed: (i) colour and perception; (ii) colour as code; (iii) colour, material, and sustainability; and (iv) colour as evidence and optimisation target in heritage and digital workflows. Across these axes, the paper identifies recurring tensions between standardisation and plurality, measurement and meaning, fidelity and interpretation, and efficiency and care. The argument advanced is that colour today should be understood not as a secondary attribute but as a critical mediator of perception, culture, ethics, and technology.

KEYWORDS Color; Perception; Design; Heritage; CMF; Digital Methods; Visual Culture

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1. Introduction

Colour research today traverses perceptual science, design and architecture, digital systems, cultural history, and heritage conservation. Across these domains, colour is increasingly treated not as a mere surface attribute but as an active mediator of experience, meaning, and material practice. Recent work ranges from low-arousal lighting strategies for neurodiversity (Bertoletti and Rossi, 2025), to immersive explorations of chromatic interaction in three-dimensional environments (Calisi and Botta, 2025), to psychological interpretations of colour as symbolic projection in modern art (Vilas Bôas and Barros de Held, 2025). At the same time, large-scale measurements of chromatic identities in public web interfaces point to colour's role in governance and institutional communication (Ahmedhodzic et al., 2025), while historical analyses of advertising posters and design movements foreground its long-standing function as a code of attention and identity (Scalzo, 2025; Spennato and Battisti, 2025).

On the material and sustainability side, systematic work on CMF design argues for the strategic role of chromo-material choices in shaping experience and durability (Sossini et al., 2025). Studies of polymeric polychromy and marbled textures reinterpret chromatic heterogeneity as a contemporary code of sustainability (Caruso et al., 2025), while research on chromatic imperfection in fashion reframes irregularity as an ethical and aesthetic resource (Calvo Ivanovic and D'Itria, 2025). Finally, heritage-oriented contributions show how colour becomes an object of evidence, optimisation, and reconstruction within restoration workflows, whether through unsupervised spatial colour algorithms (Vanoglio and Rizzi, 2025) or through documentary and scientific analyses of historical laboratory manuals (Rossetto, 2025).

Rather than surveying a single venue or issue, this article proposes a synthetic, theoretical-critical framework that connects these strands. The guiding hypothesis is that contemporary colour studies are structured by recurring tensions: standardisation versus perceptual plurality, measurement versus meaning, fidelity versus interpretation, and efficiency versus care. These tensions recur across design, heritage, digital systems, and sustainability, and they provide a productive lens for integrating otherwise distant practices.

2. An Integrative Framework

The synthesis developed here is organised around four complementary perspectives that recur across contemporary colour research.

1. Colour as perceptual variable concerns how chromatic and luminous conditions shape arousal, comfort, attention, spatial experience, and symbolic response.
2. Colour as cultural code addresses how colour operates as a semiotic and institutional device that structures identity, authority, and visibility across media and historical contexts.
3. Colour as chromo-material strategy focuses on the entanglement of colour with materials, finishes, production processes, and sustainability narratives.
4. Colour as technological and epistemic object treats colour as something measured, simulated, reconstructed, or optimised within digital and heritage workflows.

These perspectives are not disciplinary silos but analytical lenses. Many contemporary practices sit at their intersections, which is precisely what makes colour a strategic site for theoretical integration.

3. Colour as Perceptual Variable: Inclusion, Space, and Symbol

Recent research increasingly treats colour not as a secondary aesthetic attribute but as a primary perceptual variable shaping arousal, attention, comfort, and meaning. In this perspective, chromatic and luminous conditions are understood as active mediators of experience rather than neutral background parameters. Bertoletti and Rossi (2025) explicitly position light and colour within debates on inclusion by drawing on neuroscience, environmental psychology, and neurodiversity studies. Building on evidence that visual variables such as illuminance, spectral composition, flicker, and surface reflectance modulate arousal and stress (Küller et al., 2006; Boyce, 2010), they argue that many contemporary environments remain calibrated on an implicit "neurotypical" user (Manning, Williams and MacLennan, 2023). Against this backdrop, their proposal of low-arousal strategies reframes lighting and chromatic design in terms of perceptual justice: a concept that shifts the focus from average comfort to the equitable distribution of sensory load, control, and agency among users with different sensory profiles (Bertoletti and Rossi, 2025; Mostafa, 2015).

This move resonates with a broader body of work showing that poorly managed visual conditions can impair attention, increase stress, and limit participation in everyday activities (Küller et al., 2006; Westland, Pan and Lee, 2017; Rossi, 2021; Nair et al., 2022). From this standpoint, colour becomes a regulatory variable within

the environment, one that structures not only visual appearance but also behavioural and affective responses. Importantly, Bertolotti and Rossi (2025) also stress the political and ethical implications of this shift: standards and guidelines, often presented as neutral technical tools, embed normative assumptions about perception and thus risk reproducing exclusion unless they are critically re-examined and complemented by participatory and user-centred approaches.

A complementary but methodologically distinct route is taken by Calisi and Botta (2025), who revisit Josef Albers' theory of chromatic interaction through three-dimensional and virtual environments. Albers' central insight, that colour is not an intrinsic property of objects but a relational phenomenon shaped by context, is deeply rooted in Gestalt psychology, which emphasises the primacy of configuration over isolated elements (Koffka, 1935; Arnheim, 1974). By translating Albers' exercises into immersive simulations and real-time rendering, Calisi and Botta (2025) extend these classical perceptual experiments from the two-dimensional plane to spatial environments. This shift is not merely technical: it foregrounds how chromatic interactions participate in the construction of spatial experience, supporting the idea that colour can modulate perceived depth, volume, and atmosphere in architectural and virtual settings (Rossi, 2019).

Seen in this light, Calisi and Botta's contribution reinforces a relational and situational understanding of colour perception, one that aligns with contemporary views in environmental psychology and architectural theory, where space is conceived as a perceptual and affective field rather than a neutral container. Their work also highlights the role of digital tools not simply as representational media but as experimental devices for probing perceptual mechanisms, thereby bridging historical colour theory and contemporary computational design practices.

A third perspective is offered by Vilas Bôas and Barros de Held (2025), who approach colour through analytical psychology and interpret the palettes of Antônio Bandeira as projections of collective symbolic structures. Drawing on Jung's concept of the collective unconscious, they argue that chromatic choices in abstract art can be read as visual manifestations of archetypal and cultural dynamics, embedded in the *Zeitgeist* of a given historical moment. This interpretive framework resonates with earlier work on the symbolic and affective dimensions of colour (Pedrosa, 2014) and with studies that treat colour as a system of signification rather than a purely optical phenomenon (Azevedo, 2018).

Although methodologically distant from environmental design and virtual simulation, this contribution reinforces a

shared premise: colour operates at the intersection of physiological response, perceptual organisation, and meaning. Where Bertolotti and Rossi (2025) focus on sensory regulation and inclusion, and Calisi and Botta (2025) on relational perception in space, Vilas Bôas and Barros de Held (2025) foreground the symbolic and cultural layers through which colour participates in the construction of experience. Taken together, these approaches converge on a view of colour as an active, structuring variable, one that shapes how environments are felt, how spaces are perceived, and how images are interpreted.

A critical issue that emerges from this convergence concerns translation into practice. If colour is acknowledged as a powerful modulator of arousal, perception, and meaning, how can such insights inform guidelines, standards, or adaptive systems without reinstating a one-size-fits-all model of perception? The tension identified by Bertolotti and Rossi (2025) between standardisation and perceptual plurality is therefore not merely technical but epistemic and ethical: it calls for design frameworks capable of accommodating variability, context, and user agency while still operating within institutional and regulatory structures.

4. Colour as Cultural Code: Identity, Attention, and Governance

In contemporary visual culture, colour increasingly operates as an infrastructural element of communication systems, where identity, recognisability, and legitimacy are negotiated through chromatic choices. Large-scale analyses of public interfaces illustrate how colour functions not merely as an aesthetic layer but as a semiotic and organisational device embedded in institutional governance. Ahmedhodzic et al. (2025) conceptualise header colours in Italian municipal websites as a measurable proxy for identity and policy implementation, showing how chromatic selections are shaped by the tension between local distinctiveness, visual coherence, and technical standardisation. Their approach resonates with broader traditions in visual semiotics and information design, where colour is understood as a carrier of meaning, hierarchy, and authority within complex communication systems (Kress and van Leeuwen, 2002). From this perspective, institutional colour systems can be read as instruments of governance that stabilise expectations, support navigability, and signal legitimacy, while simultaneously constraining expressive variation. The quantitative mapping proposed by Ahmedhodzic et al. (2025) thus extends earlier work on corporate and public visual identity, where colour palettes operate as tools for recognition, trust-building, and symbolic continuity across

media (Heller and Vienne, 2012). At the same time, their findings expose the fragility of this balance: excessive standardisation risks erasing local specificity, whereas excessive variation undermines coherence and usability.

Historical analyses provide a longer genealogy of colour as a technology of attention. Scalzo (2025) traces the introduction of black backgrounds in early twentieth-century advertising posters, particularly in the work of Leonetto Cappiello, as a decisive shift toward a visual grammar based on contrast, immediacy, and perceptual impact. This strategy, grounded in the need for rapid legibility in urban visual environments, aligns with earlier theories of poster design and advertising that emphasised shock, memorability, and visual salience as key drivers of attention (Wlassikoff, 2008). The black background, by maximising chromatic contrast, transformed colour into an active agent of visual capture, anticipating many of the high-impact strategies still operative in contemporary visual communication and interface design.

Spennato and Battisti (2025) situate these developments within the broader history of design movements, showing how colour has oscillated between a subordinate, rationalised role, typical of functionalist and modernist paradigms, and an expressive marker of identity, emotion, and cultural values in more eclectic and postmodern phases. Their analysis echoes classic accounts of modern design culture, where the regulation of colour was often tied to ideals of objectivity, efficiency, and universality, while later reactions reasserted colour as a vehicle of plurality, symbolism, and differentiation (Meggs and Purvis, 2016).

Taken together, these contributions suggest that colour as cultural code operates across multiple temporal and institutional scales: from the historical technologies of attention developed in mass advertising (Scalzo, 2025), to the ideological frameworks of design movements (Spennato and Battisti, 2025), to the contemporary governance of digital public interfaces (Ahmedhodzic et al., 2025). Across these contexts, a persistent tension emerges between standardisation and expressivity, between colour as a tool of control and colour as a marker of identity, a tension that remains central to understanding visual culture in both historical and digital environments.

5. Colour as Chromo-Material Strategy: CMF, Polychromy, Imperfection

In contemporary design discourse, colour is increasingly understood as inseparable from material and surface, giving rise to the notion of CMF as a strategic design domain rather than a purely aesthetic layer. Sossini et al. (2025) provide a systematic mapping of CMF design

research and argue that chromo-material decisions play a central role in shaping product identity, user experience, and long-term engagement. By framing CMF as an integrated design strategy, their review aligns with a broader shift in design research that treats materials not as passive substrates but as active carriers of meaning, performance, and value (Ashby and Johnson, 2014; Karana et al., 2015; Manzini, 2015). In this perspective, colour is not added to form and material at the end of the process, but participates from the outset in constructing how products are perceived, used, and evaluated over time. This strategic understanding of CMF also intersects with sustainability debates. Sossini et al. (2025) highlight how chromo-material choices influence perceived quality, attachment, and durability, factors that are increasingly recognised as crucial for extending product lifecycles and reducing premature disposal (Mugge, Schoormans and Schifferstein, 2005). Here, colour and finish are not merely expressive tools but levers for shaping user-object relationships and, indirectly, consumption patterns.

Caruso et al. (2025) push this argument further by analysing polymeric polychromy and marbled textures as a contemporary code of sustainability. Their work situates chromatic heterogeneity within the context of open recycling and decentralised production, where material mixtures and colour variability are no longer treated as defects to be eliminated but as visible traces of circular processes. This position resonates with emerging theories of circular design and material aesthetics, which argue for making material histories legible rather than hiding them behind uniform surfaces (Bocken et al., 2016; Karana et al., 2018). In this sense, marbled and heterogeneous surfaces operate as semiotic devices: they signal recycled content, process openness, and a departure from the industrial ideal of perfect repeatability.

A similar revaluation of non-uniformity underpins Calvo Ivanovic and D'Itria's (2025) discussion of chromatic imperfection in fashion. Drawing on both design theory and sustainability studies, they argue that irregularities, variations, and chromatic "defects" can function as ethical and aesthetic resources rather than as quality failures. By making imperfection visible, such strategies can communicate material provenance, craft processes, and extended lifecycles, fostering forms of attachment that counteract disposability (Fletcher, 2014; Niinimäki, 2015). This approach also echoes broader cultural shifts in which patina, wear, and variation are increasingly valued as signs of authenticity and time, rather than as problems to be erased (Ingold, 2011).

Taken together, these contributions suggest a paradigmatic shift away from the industrial ideal of uniformity toward a chromo-material culture in which

variation, texture, and imperfection acquire positive value (Sossini et al., 2025; Caruso et al., 2025; Calvo Ivanovic and D'Itria, 2025). However, this shift raises a critical question: how can such aesthetics be scaled and institutionalised without losing their ecological and ethical significance? If heterogeneity becomes merely a new stylistic norm, detached from material processes and circular logics, its critical potential risks being neutralised. The challenge, therefore, is not only formal but systemic: to align chromo-material strategies with production models, supply chains, and user practices that genuinely support sustainability rather than simply rebranding it.

6. Colour as Technological and Epistemic Object: Restoration, Manuals, Algorithms

In heritage and digital workflows, colour increasingly emerges not only as a visual attribute to be preserved or displayed, but as a technological and epistemic object, something to be measured, reconstructed, optimised, and validated. Within this framework, Vanoglio and Rizzi (2025) conceptualise colour restoration as a problem of constrained optimisation. By comparing supervised workflows with unsupervised spatial colour algorithms, they argue that automated approaches can improve sustainability and accessibility for small cinematheques, albeit at the cost of a controlled reduction in quality. Colour is thus explicitly framed as an optimisation target within a technical, economic, and institutional system characterised by limited resources and competing priorities. This position aligns with a long tradition in digital image processing and colour science, where restoration is understood as a trade-off between fidelity, computational cost, and robustness (Rizzi, Gatta and Marini, 2009). In the context of cultural heritage, such trade-offs acquire a normative dimension: decisions about colour correction, enhancement, or reconstruction are never purely technical, but embed assumptions about acceptable loss, intended use, and audience expectations (Fossati, 2009). Vanoglio and Rizzi's (2025) proposal to favour scalable, unsupervised methods for small archives, therefore situates algorithmic choices within a broader ethics of access and sustainability, rather than within a narrow paradigm of maximal visual accuracy.

Rossetto (2025) approaches colour from a different but complementary epistemic angle: as material evidence to be reconstructed through documentary sources and scientific analysis. Focusing on silent film, Rossetto shows how historical laboratory manuals, chemical formulas, and spectroscopic data can be mobilised to characterise and validate historical colour processes. This approach resonates with established practices in conservation science and film archiving, where the reconstruction of

historical appearance relies on the triangulation of textual sources, material analysis, and comparative study of surviving artefacts (Read and Meyer, 2000; Fossati, 2009). Here, colour is not primarily an optimisation variable, but an object of historical inquiry whose legitimacy depends on evidential chains and methodological transparency.

The contrast between these two approaches brings into focus a fundamental tension in contemporary heritage practice: optimisation versus reconstruction, efficiency versus evidential care (Vanoglio and Rizzi, 2025; Rossetto, 2025). On the one hand, algorithmic methods promise scalability, repeatability, and resource efficiency, values that are increasingly central in a context of growing digitisation and limited funding. On the other hand, evidence-based reconstruction insists on the irreducibility of historical specificity and on the need for slow, interpretative, and materially grounded work. This tension is not merely operational but epistemological: it concerns what counts as "the" colour of a historical object, who is entitled to decide, and for which purposes.

Read together, these contributions show that colour in heritage contexts is inseparable from broader questions of authenticity, access, and use. Whether treated as an optimisation target within algorithmic pipelines or as material evidence reconstructed from archival sources, colour becomes a site where technical constraints, historical knowledge, and institutional missions intersect. The challenge for future research is therefore not to choose between automation and reconstruction, but to articulate hybrid frameworks in which computational tools and evidential practices can inform and critically constrain one another.

7. Conclusions

This article has argued for a theoretical-critical understanding of colour as a mediator across design, heritage, digital systems, and sustainability. Read through the four lenses proposed here, contemporary work shows how chromatic decisions distribute sensory load and agency (Bertoletti and Rossi, 2025), organise institutional and cultural identities (Ahmedhodzic et al., 2025; Spennato and Battisti, 2025), encode material-ethical values (Sossini et al., 2025; Caruso et al., 2025; Calvo Ivanovic and D'Itria, 2025), and are increasingly shaped by algorithmic and evidence-based workflows (Vanoglio and Rizzi, 2025; Rossetto, 2025). Future research would benefit from strengthening links between perceptual justice, design governance, sustainable material practices, and heritage evidence, while also developing hybrid methods that can negotiate quantitative measurement and qualitative interpretation.

8. Conflict of interest declaration

The author declare no conflict of interest.

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10. Short biography of the author

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