Color and Colorimetry
Multidisciplinary Contributions

Vol. XX A

Edited by Filippo Cherubini and Andrea Siniscalco

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Introduction

The Color Conference, organized annually by the Italian Color Association (Gruppo del Colore - Associazione Italiana Colore), reached its Twentieth Edition in 2025.
The international two-day event took place on September 4th and 5th, 2025, at the University of Naples Parthenope in the beautiful city of Naples.

This milestone edition opened with three keynote presentations of exceptional breadth and inspiration. The conference began with Dr. Costanza Miliani from the CNR Institute of Heritage Science, who presented "Writing with Colors: Materials, Techniques, and Cultural Significance in Mesoamerican Codices". The program continued with Studio Waldemeyer, featuring Farahbod Nazanin and Moritz Waldemeyer, and their evocative talk "Where Light Becomes Emotion".
The morning session concluded with the Color Award 2025, conferred to Massimo Cantini Parrini in recognition of his extraordinary contribution to the world of costume and creativity.
The following day opened with an outstanding invited lecture by Dr. Massimiliano Guarnieri from ENEA, who presented "Artificial Intelligence and color features detection: some examples and future perspective".

Sincere thanks go to the Chairs of the Conference, Giuliana Ramella (CNR – Institute for Applied Calculus "Mauro Picone") Francesca Fragliasso (University of Naples Federico II) and Andrea Siniscalco (Dipartimento di Design, Politecnico di Milano), for their valuable guidance and coordination. A heartfelt appreciation also goes to the University of Naples Parthenope, host of this year's edition.
We warmly thank Dr. Sofia Ceccarelli (CNR ISPC) for the local organization, the Program Committee, Professors Angelo Ciaramella and Emanuel Di Nardo (University of Naples Parthenope), Professors Laura Bellia and Francesca Diglio (University of Naples Federico II), as well as Dr. Filippo Cherubini, Secretary of the Association, and all the members of the Scientific Committee, for their fundamental contribution to the dissemination, review, and organization of the conference. Special thanks also go to Tectilia, the event sponsor, whose support helped make this conference both culturally enriching and welcoming.

The 2025 program once again confirmed the richness and interdisciplinarity that have always characterized the work of our community, spanning from design to education, and from cultural heritage to psychology.
These diverse perspectives continue to make the Conferenza del Colore a reference point for researchers, professionals, and enthusiasts working on the multifaceted study of color.

Finally, we extend our gratitude to all authors and speakers for the quality of their contributions, and to the institutions and associations that offered their patronage and collaboration, reinforcing the spirit of unity that defines this event.

The following pages collect the proceedings of the Twentieth Color Conference.

We wish you an inspiring read.

Alice Plutino
October 2025

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Keynote Speakers

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Artificial Intelligence and color features detection: some examples and future perspective

Massimiliano Guarneri

Abstract

The integration of artificial intelligence (AI) with colorimetric analysis has emerged in the last years in several sectors, and in particular in cultural heritage monitoring and research, revolutionizing traditional approaches to color feature extraction, pigment identification, and photorealistic 3D digital twins. The present work will show, throught the use of examples, how the AI algorithms are solving different problems by enhancing colorimetric information in environments where it is strongly compromised, i.e. in underwater environments, or using colorimetric spectra for searching features helping the experts interpretation of vanishing pictorial details. As mentioned before, another field where the AI approach is making the difference is the reproduction of 3D digital twins: in this case these algorithms are allowing the reproduction of reflectrive and refractive information, not possible since few years ago.

Short Bio

Massimiliano Guarneri is an Italian researcher, with a degree in Physics, a PhD in mechanical measurements engineering and a master in 3D design and animation. His background is focused on Artificial Vision and development of optical prototypes, particularly multi-wavelength radar for simultaneous structural and colorimetric information acquisition. Throughout his career, he has focused on applications within both the nuclear and Cultural Heritage sectors, as well as underwater environments. This interdisciplinary approach has yielded nationally and internationally recognized results.

Writing with Colors: Materials, Techniques, and Cultural Significance in Mesoamerican Codices

Costanza Miliani

Abstract

This paper explores the material dimension of color in Mesoamerican pictorial manuscripts, combining non-invasive scientific analysis with historical and cultural perspectives. Focusing on a selection of pre-Hispanic and early colonial codices — including the Codex Cospi, Codex Madrid, and other Mixtec and Nahua examples — the study investigates how coloring materials, application techniques, and support preparation reveal codified scribal practices and cultural transmission.Mobile platforms (MOLAB @ E-RIHS) enabled in situ investigations using XRF, FORS, Raman, and FTIR spectroscopy, identifying a recurrent palette based on gypsum grounds, carbon black, cochineal, ochres, and the hybrid pigment Maya Blue. Interpreted alongside early colonial sources, these data show how pigments were not decorative alone, but embedded with cosmological, ritual, and social meaning. Variations in composition, layering, and binders across manuscripts point to shared protocols and regional choices. Beyond technical insights, this contributes to understanding color as both material and epistemic in indigenous visual languages.

The paper closes with reflections on heritage communication, highlighting the MagicLens Codex Cospi installation (LACMA, Los Angeles), which connects scientific research with multisensory public access.

Short Bio

Costanza Miliani completed her studies at the University of Perugia, earning a degree in Chemical Sciences in 1995 and a PhD in 1999. She later expanded her expertise with an Executive Master in Management of Research Infrastructures from the University of Milano-Bicocca in 2019. Her research focuses primarily on the study of polychromies in art, investigating both execution techniques and alteration processes, contributing significantly to the understanding of color in cultural heritage. Miliani has authored over 240 scientific publications, achieving an h-index of 57 and over 9,000 citations according to Google Scholar. She co-edited the book Science and Art: The Painted Surface, published by the Royal Society of Chemistry, and serves on the editorial board of the open-access journal Heritage. She has led numerous regional, national, and European research projects, with a strong interdisciplinary approach.

Currently, she directs the European mobile platform MOLAB, providing access to non-invasive mobile laboratories for heritage science researchers, and coordinates the Italian node of E-RIHS (European Research Infrastructure for Heritage Science).

Her work emphasizes the application of advanced analytical techniques to study pigments, binders, and the complex interactions underlying the aging of color in artworks. Miliani is a board member of SMAArt (Scientific Methodologies applied to Archaeology and Art) at the University of Perugia, the Cultural Heritage Technological District of Lazio, and the scientific advisory board of the Center for Scientific Studies in the Arts at Northwestern University in Chicago. Since 2019, she has served as Director of the Institute of Heritage Science (CNR-ISPC), where she continues to advance research in color science and the preservation of polychromatic artworks.

References

Buti et al. 2011, J. Arch. Sci.; Domenici 2018; Miliani et al. 2014, Science and Art.

Acknowledgments

This research is part of CHANGES (PE5, PNRR, EU–NextGenEU), PRIN KNOT (2022), and E-RIHS.

Where Light Becomes Emotion

Moritz Waldemeyer, Nazanin Farahbod

Abstract

In Studio Waldemeyer's atelier, light transcends visibility—it resonates. We, Moritz Waldemeyer and Nazanin Farahbod, guide our creative exploration toward light's soul: its chromatic breath, its emotional texture, its capacity to stir memory and seed stories.

Our Foundations – Moritz emerged from East Germany, where material scarcity cultivated creative resilience. In London, his mechatronics studies at King's College crystallised his vision: light as data, emotion as current, colour as a language of intention.

Nazanin's story began amid Iranian blackouts, where a flickering candle was a fragile lifeline. That childhood memory—of warmth kindled against darkness—informs our belief in light as symbol and comfort. Her journey wound through coding in Iran to industrial and product design in Milan, bringing technology and personal narrative together.

Light, in Our Hands – We sculpt light as a potter moulds clay: tenderly, responsively, alive. In the Mythos Mozart installation in Vienna, 1,500 individually animated LED candles pulse in sync with Mozart's final music—each flicker a whispered soul. When the moment of his passing arrives, the flames collectively extinguish, then slowly reignite—evoking legacy, grief, and hope.

Our Process – Each project springs from wonder: What does coloured light feel like when suspended above an altar? In St Stephen Walbrook Church, our rotating Halo created a moving halo of light—a meditative presence, fusing geometry and stillness.

In our London studio, we prototype rapidly, forging alchemy through colour, light, memory, and craft.

During the conference, we will speak of colour as emotional architecture—where hue, rhythm, and resonance shape a space's heartbeat. Through tales of candles that breathe, halos that meditate, we will share our belief: coloured light is not ornament—it is a living presence.

We invite the Associazione Italiana Colore to step into our world, where every shade is feeling, every glow is memory, and every beam is a dialogue between human and light.

Short Bio

Moritz Waldemeyer is an accomplished designer and engineer whose career has been defined by a distinctive blend of creativity, technology, and practical know-how. With a background in engineering and early collaborations with design visionaries like Ron Arad and Zaha Hadid, he has continuously pushed the boundaries of interactive and experiential design. This unique perspective—combining technical rigour with imaginative storytelling—positions him perfectly to contribute to the Queen Elizabeth National Monument's design team, ensuring a solution that is not only inspiring and respectful of Her Majesty's legacy, but also flawlessly executed to withstand the test of time.

Nazanin Farahbod brings a richly layered perspective to the design team, shaped by her upbringing in Tehran, her formal product design studies in Milan, and eight years of hands-on experience at Studio Waldemeyer. Her artistic sensitivity—evident in her practice of painting in the Persian miniature tradition and exhibiting work at the Royal Academy—enables her to blend historical influences with contemporary design thinking. This cultural fluency and creative insight position her to craft meaningful, visually compelling narratives that honour the memory of Queen Elizabeth while engaging a diverse, global audience.

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Color in Measurement - Color in Digital

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Color Difference Evaluation on Textiles: A Comparative Study of CIE76 and CMC(l:c) with Respect to Surface Topography

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Abstract

The accurate evaluation of colour differences on textiles remains challenging due to the influence of surface texture and morphology on colour appearance. This study investigates five cotton fabrics of different weave constructions (plain, twill, mixed panama, basket, satin) printed with reactive dyes using digital inkjet technology. Fabric texture and roughness were quantified by digital image analysis and microscopy, while colourimetric parameters were measured spectrophotometrically. Colour differences were calculated with CIE76, CMC (l:c), and CIEDE2000 formulas. Results show that colour differences for green are distributed across lightness, chroma, and hue, whereas for yellow they are almost exclusively chroma-driven. CMC (l:c) consistently reduced differences compared to CIE76 by down-weighting hue and chroma, while CIEDE2000 yielded the lowest overall ΔE values. These findings confirm that the choice of formula significantly affects the interpretation of colour differences on structured textiles. Moreover, recent evidence indicates that CIEDE2000, although the most perceptually uniform for flat samples, may underestimate differences on heterogeneous surfaces, suggesting that CMC retains practical relevance in textile colour evaluation.

Keywords: Colour difference, CIE76, CMC (l:c), CIEDE2000, textile surface texture, digital printing, colour perception

Introduction

Over the past decades, several mathematical models have been proposed to quantify perceptible differences between colours. The earliest, CIE76 (ΔE*ab), calculates Euclidean distance in CIELAB space, but its lack of perceptual uniformity often leads to under/or overestimation of differences in specific regions of colour space. To improve tolerance assessment, the CMC (l:c) formula was introduced in 1984, providing separate weighting factors for lightness and chroma and rapidly becoming a standard in the textile industry. The most advanced model, CIEDE2000, incorporates additional corrections for lightness, chroma, and hue, together with a rotation term addressing deficiencies in the blue region (Cinko and Becerir, 2024; Luo M.R. and Rigg B., 2008; Kuo, W., 2010). Comparative studies (Luo et al., 2001; Gibert et al., 2005; Melgosa, 2012;) have shown that ΔE_{00} provides the best overall agreement with visual assessments for flat, homogeneous samples. However, the majority of these models were derived and validated under controlled conditions that did not consider the morphological and optical heterogeneity of textile surfaces. The complexity and inhomogeneity of woven fabrics affect their surface properties and consequently strongly influence droplet shape, spreading speed, and penetration of ink during digital printing (Romdhani et al., 2017; Brnada et al., 2022). Several studies (Moussa et al., 2008; Gorji Kandi et al., 2008; Huertas et al., 2006; Xin et al., 2005; Tkalec et al., 2024) have demonstrated a direct dependence of colour appearance on the topographical and morphological properties of textiles, confirming that surface roughness, porosity, and fibre orientation play a decisive role. These characteristics not only affect the uniformity of dye distribution but also cause anisotropic reflection and scattering, thereby altering both subjective perception and instrumental evaluation of colour. Therefore, despite the long tradition of comparative studies on colour-difference formulas, the identification of the most appropriate formula to interpret colour differences arising specifically from the effect of textile texture remains

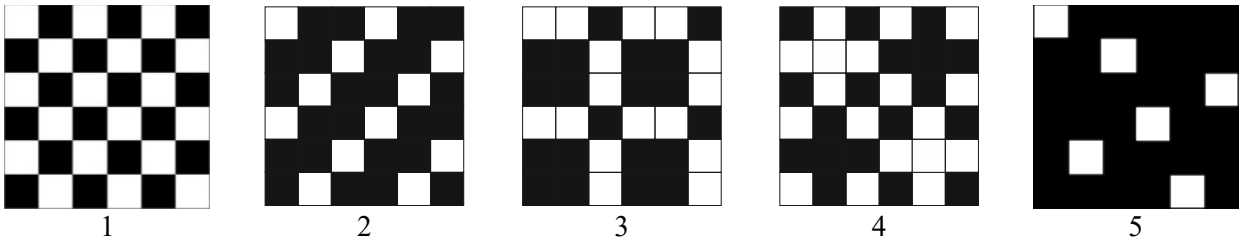
an open and important research question. It remains uncertain whether formulas optimised for smooth, flat samples (such as ΔE_{00} can fully capture perceptual differences induced by textile texture. A formula like CMC (l:c), which gives higher weight to lightness differences, may yield different outcomes compared to CIEDE2000, which more strongly adjusts for hue-chroma interactions. Therefore, the selection and critical evaluation of colour-difference formulas become essential when assessing the influence of textile texture on colour reproduction.

Materials and methods

To analyse the interaction between textile structure and colour, samples of 100% cotton fabrics were used. The samples were produced as part of a broader research project, of which only a portion is presented in this paper. They were manufactured by the Croatian textile company Čateks Industry using identical yarns but with varying construction parameters, resulting in fabrics of different structures and textures. Five weave constructions were applied: (1) Plain weave 1/1, (2) Twill weave 2/1, (3) Mixed panama 2/1, (4) Basket weave, and (5) Satin weave 5/1. The structural parameters of the fabrics are given in Table 1, while schematic representations of the weaves are shown in Fig. 1. Fabric surface structures were further examined by digital microscopy, with images presented in Fig. 2.

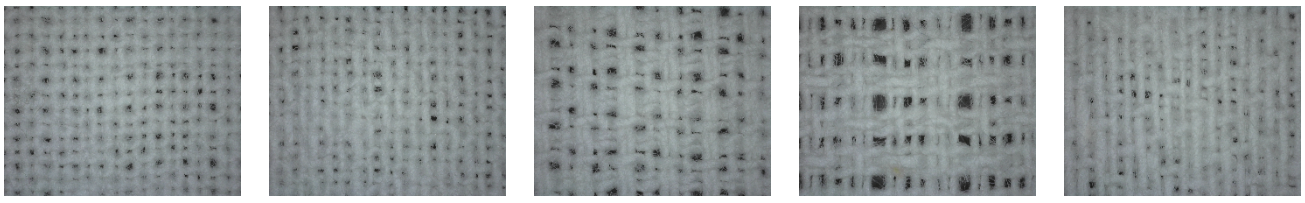
Table 1. Structural parameters of selected fabrics

Samples	**The fineness of the warp [tex]**	**The fineness of the weft [tex]**	**Warp density [threads/cm]**	**Weft density [threads/cm]**	**Mass [g/m^2]**
1 Plain weave 1/1	36	36	22	24	170,95
2 Twill weave 2/1	36	36	22	24	173,45
3 Mixed panama 2/1	36	36	22	24	173,02
4 Basket weave	36	36	22	24	167,89
5 Satin weave 5/1	36	36	22	24	170,91



1 2 3 4 5

Fig. 1 Construction weaves of selected fabrics: (1) Plain weave 1/1, (2) Twill weave 2/1, (3) Mixed panama 2/1, (4) Basket weave, (5) Satin weave 5/1



1 2 3 4 5

Fig. 2 Microscopic images of samples structure: (1) Plain weave 1/1, (2) Twill weave 2/1, (3) Mixed panama 2/1, (4) Basket weave, (5) Satin weave 5/1

Data on fabric roughness and texture were obtained using ImageJ software, specifically the *GLCM Texture* and *SurfCharJ 1q* plugins, while 3D visualizations of fabric structures were generated with

the 3D Interactive Surface Plot plugin (Fig. 3). Prior to printing, the fabrics were pretreated by impregnation with an aqueous solution containing 800 g thickener (CHT Alginate EHV 3%)**,** 100 g urea**,** 20 g Ludigol (BASF, organic oxidant)**,** 50 g $NaHCO_3$, and 1030 g water, followed by drying. Digital printing was then carried out on the pretreated fabrics using a Mimaki Tx2-1600 inkjet printer (Mimaki, Japan) with reactive dyes. After printing, the samples underwent steam fixation, washing, and drying. A multicoloured test image created in AdoGLCM Texture and SurfCharJ 1q be Illustrator (Fig. 4a) was printed and the resulting textile print is shown in Figure 4b, from which green and yellow regions were selected for further analysis. Finally, the printed samples were examined by microscopic imaging (Dino Lite AM-7013MZT) (Fig. 5), and by spectrophotometric measurements of colour characteristics (Datacolor 850 remission spectrophotometer, 2.5 cm aperture, d/8° geometry). The microscopic images of printed colors on selected samples are shown in Fig. 5, while the results of color quantification are shown by placing the color printed on the samples in a*/b* color space on Fig. 6. Results of the K/S values and L*, C*, h° parameters are shown in Table 4 and 5. The color difference is calculated according to CIE76, CMC(l:c) and CIEDE200 formulae. The results are shown in Tables 6 and 7.

Results and Discussion

By conducting an image analysis of the selected fabrics, an insight into the characteristics of their parameters of textures and roughness were obtained. The results that provide information about the texture of the scanned fabrics, are presented in Table 2. The results of the parameters that describe the roughness of the samples are found in Table 3. Figure 3 shows the appearance of the surface texture of fabrics, created using the 3D Interactive Surface Plot plugin in the ImageJ program.

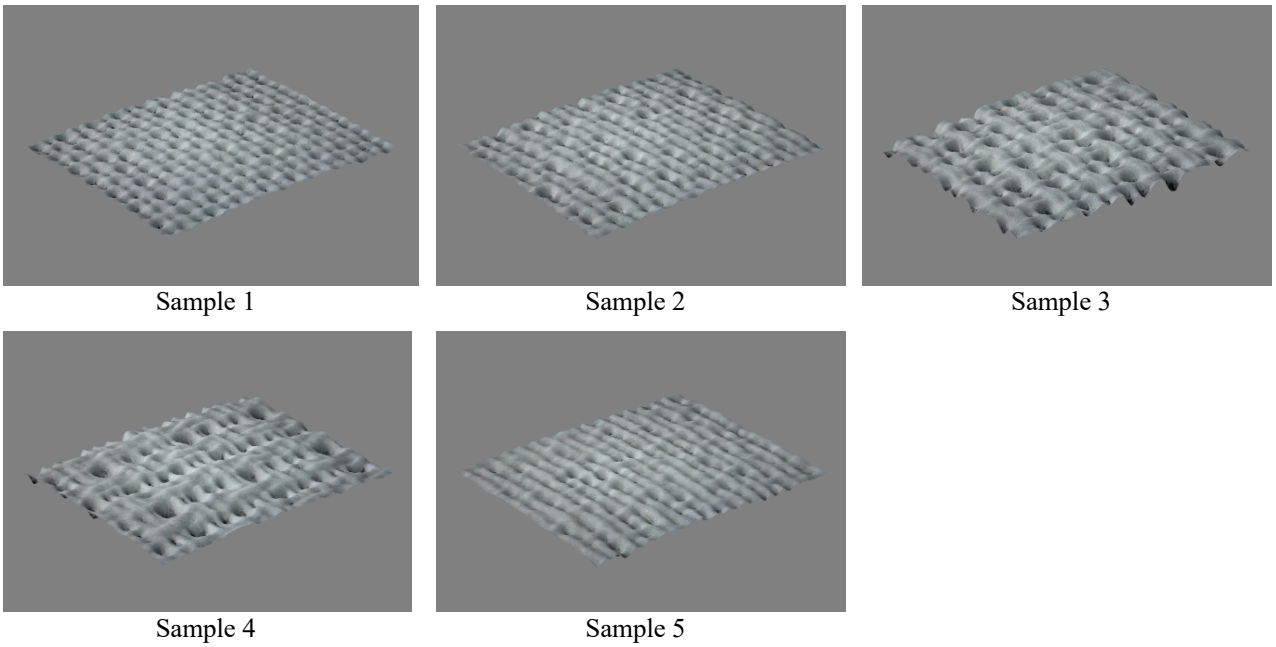


Fig. 3 3D surface images of fabrics using ImageJ's 3D Interactive Surface Plot plugin

By comparing the surfaces of various fabric structures, noticeable differences in the appearance of the image surface can be observed, depending on the type of texture. The 3D Interactive Surface Plot plugin enables the creation of interactive 3D surfaces from all types of images, in this case, fabric surfaces with different textures. Using this plugin, realistic representations of fabric surfaces with diverse structures were generated, clearly illustrating the irregularity, inhomogeneity, and non-uniformity of the textile surface. These characteristics significantly influence processes that fabrics undergo, such as color reproduction in digital printing, as examined in this research.

Table 2. GLCM texture parameters from ImageJ program

Samples	ASM	Contrast	Correlation	IDM	Entropy
1 Plain weave 1/1	0.0014	55.88	0.0027	0.248	7.201
2 Twill weave 2/1	0.0013	54.88	0.0028	0.246	7.212
3 Mixed panama 2/1	0.0012	**57.52**	0.0018	**0.245**	7.387
4 Basket weave	0.0012	**59.01**	0.0015	**0.247**	7.428
5 Satin weave 5/1	0.0014	**51.84**	0.0030	**0.255**	7.142

Table 3. Roughness parameters from ImageJ program

Samples	Rq	Ra	Rsk	Rku	Rv	Rp	Rt
1 Plain weave 1/1	18.61	13.22	-1.70	6.03	-138.35	66.06	204.41
2 Twill weave 2/1	19.07	13.19	-1.92	7.45	-139.42	67.87	207.29
3 Mixed panama 2/1	22.99	**15.73**	-1.83	4.80	-138.29	63.82	202.11
4 Basket weave	25.75	**17.36**	-1.90	4.46	-139.41	69.09	208.50
5 Satin weave 5/1	15.88	**11.56**	-1.49	6.86	-141.43	61.49	202.92

The image analysis of fabrics yielded the following values describing the texture: ASM (energy or uniformity), contrast, correlation, IDM or homogeneity, and entropy. The values of the contrast parameter, which describes the differences in intensity between a reference pixel and its neighbor, were analyzed, measuring variations within the image. Lower contrast values indicate uniform surfaces, while higher values are characteristic of textures with pronounced differences in pixel intensity (Jurič, 2018). According to the results, it was determined that sample 4 (59.01, basket weave) and sample 10 (57.52, mixed panama 2/1) have the highest contrast values. Sample 1 (51.84, satin weave 5/1) has the lowest value. According to the results, fabrics with lower values of the contrast parameter have more uniform surfaces. According to the Ra value, the average roughness of the surface, when comparing the roughness of samples of the different structures, the analysis of the results determined that the lowest Ra value is for sample 1 (11.56, satin weave 5/1). The highest Ra values are for sample 4 (17.36, basket weave) and sample 3 (15.73, mixed panama 2/1). The highest roughness values are in accordance with the values of the texture (contrast) parameter that describes the uniformity, or unevenness, of the surface.

To illustrate the workflow, Fig. 4 shows the test design created in Adobe Illustrator (a), the two colours selected for further analysis with their corresponding CMYK definitions (b), and the digitally printed sample on the reference fabric (Plain weave 1/1) (c). These visual representations provide the basis for analysing how structural differences among fabrics affect colour reproduction.

(a) (b) (c)

Fig. 4 (a) Image created in Adobe Illustrator; (b) Colors chosen from the image for further analysis; (c) Image digitally printed on the textile substrate

Microscopic images show a visible interaction of the topographic characteristics of fabrics—the fabric structure and the colors obtained by printing. Irregularities in the mixing of process (CMYK) colors are also visible, which are caused precisely by the influence of the structure that prevents proper positioning and consequently optimal mixing of process colors according to the requirements of the image. The influence of crossover points and places where the mixing of process colors did not occur at all is visible, but points of individual components are also present. Therefore, the influence of the substrate is evident; this is confirmed by the differences in the quality of reproduction and the appearance of colors. The characteristics and shape of the capillary spread of color are different in all samples. Also, the quality of reproduction of the sharpness of the contour, which is irregular, is a consequence of different types of structures, non-uniform inhomogeneous surfaces, and irregular yarns defined by certain characteristics.

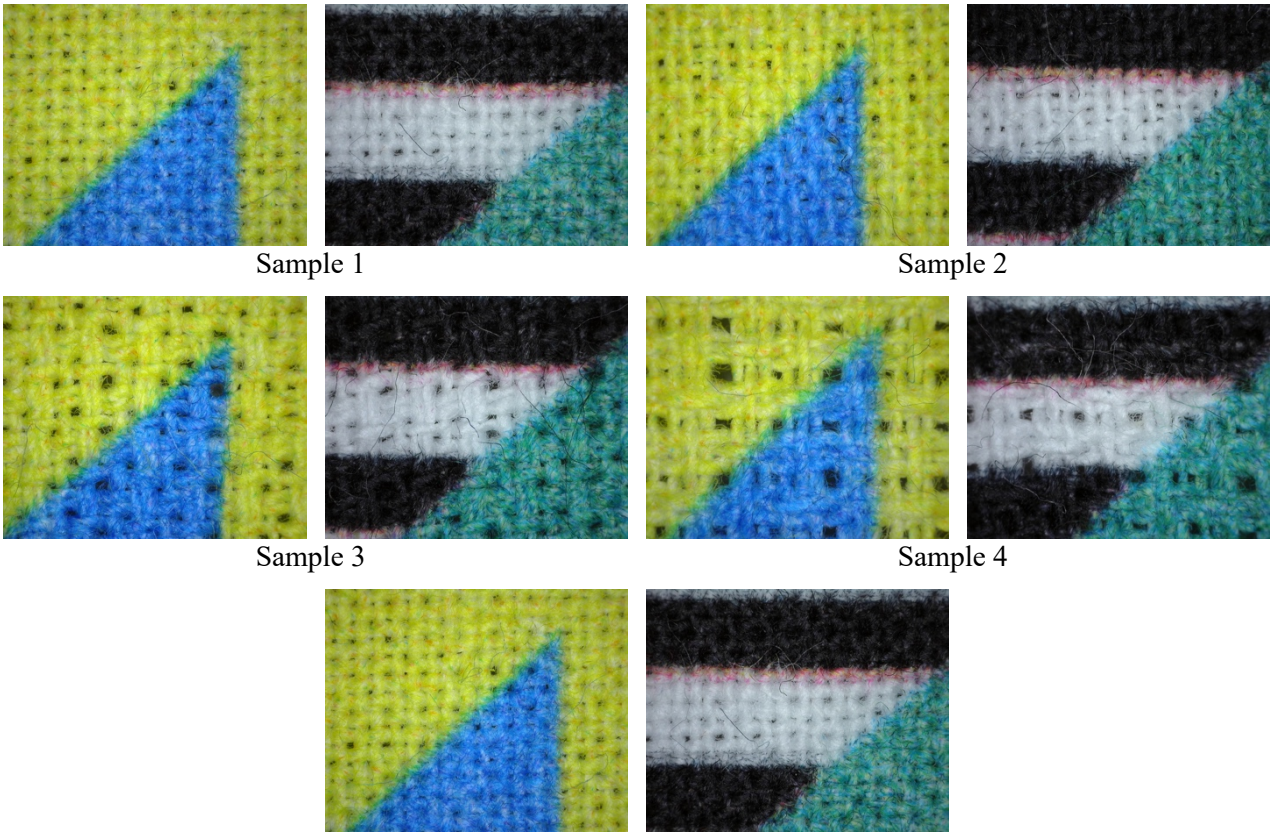


Fig. 5 Microscopic imaging performed by digital microscope Dino-Lite

The Kubelka–Munk (K/S) values (Table 4), demonstrate a clear dependence on fabric structure. For both analysed colours, green and yellow, the lowest K/S values were obtained for the satin weave (sample 5), indicating the weakest dye uptake, while the highest values were recorded for the mixed panama 2/1 (sample 3).

Table 4. K/S parameters of the measured colors

Samples	**Green**		**Yellow**	
	K/S	**λ (nm)**	**K/S**	**λ (nm)**
1 Plain weave 1/1	4.6	510	3.2	670
2 Twill weave 2/1	5.0	510	4.1	670
3 Mixed panama 2/1	5.7	510	3.9	670

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4 Basket weave	5.0	510	3.0	670
5 Satin weave 5/1	3.2	510	2.8	670

In the case of green, the maximum K/S (5.7) was measured for mixed panama, whereas for yellow the maximum K/S (4.1) appeared in the twill weave 2/1 (sample 2). The observed differences confirm that structural characteristics of woven fabrics strongly influence light absorption and reflectance, and consequently the perceived colour strength. This is consistent with the Kubelka–Munk theory, where the interaction of incident light with the coloured textile surface is governed not only by dye chemistry but also by the fabric's morphology. The higher K/S values for green can be attributed to subtractive mixing of yellow and cyan components, which enhances absorption in the red–blue region and increases reflection in the green region. In contrast, yellow exhibits generally lower K/S values due to its spectral behaviour, reflecting a large proportion of incident light while absorbing mainly in the blue region around 430 nm.

In the a*/b* color space shown in Fig. 6, a certain variability of the a* and b* values of the measured colors is observed. The differences observed within the same color appear due to the different structural characteristics of the textile fabrics.

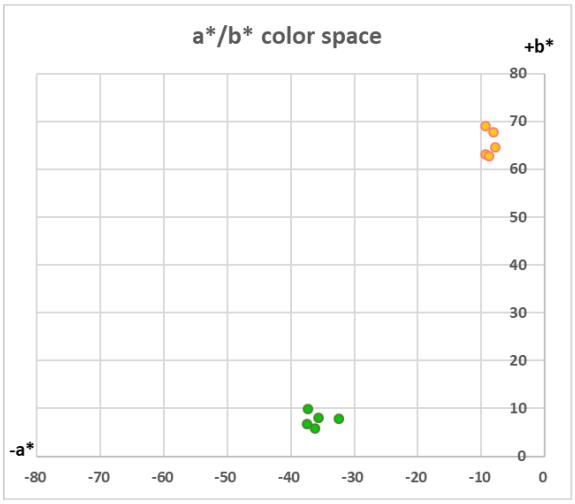

Fig. 6 Results of spectrophotometric measurement: values of the printed samples placed in a*/b* color space

Table 5. Objective values of color parameters (L*, C*, h°) for green and yellow color

	Green			Yellow		
Samples	**L***	**C***	**h°**	**L***	**C***	**h°**
1 (Plain weave 1/1)	65.9	36.4	167.4	87.1	65.0	96.9
2 (Twill weave 2/1)	64.8	38.6	165.2	87.4	69.6	97.7
3 (Mixed panama 2/1)	62.9	37.9	169.8	87.0	68.2	96.8
4 (Basket weave)	65.1	36.6	171.0	87.4	63.3	98.0
5 (Satin weave 5/1)	68.2	33.3	166.4	88.0	63.8	98.4

Tables 6 and 7 present the calculated colour differences for green and yellow, respectively, with the pPlain weave 1/1 (**1**) sample taken as the reference. The comparison was carried out to evaluate how much the texture and morphology of the textile surface influence the resulting colour differences. To capture this effect, three colour-difference formulas were applied: CIE76, CMC (l:c), and CIEDE2000. Given that these formulas differ in their conceptual approach, ranging from the simple Euclidean distance of CIE76, to the lightness–chroma weighting of CMC, and finally the perceptual

corrections of CIEDE2000, the intention was to examine how each would respond to pronounced structural variations among the fabrics.

Table 6. Color difference comparison of samples according to CMC(l:c) i CIE76 systems for green color

Standard: 1 Plain weave 1/1, **Green color**												
	CIE76				**CMC(l:c)**				**CIEDE2000**			
Samples	**ΔL***	**ΔC***	**Δh**	**ΔE**	**ΔL*/Sl**	**ΔC*/Sc**	**Δh/Sh**	**ΔE**	**ΔL_{00}**	**ΔC^*_{00}**	**Δh_{00}**	**ΔE_{00}**
2	-1.1	2.1	-1.4	2.8	-0.4	0.9	-0.9	1.4	-1.1	2.2	-2.2	1.5
3	-3.0	1.5	1.6	3.7	-1.2	0.7	0.9	1.7	-3.0	1.5	2.4	2.7
4	-0.8	0.1	2.3	2.6	-0.3	0.1	1.4	1.5	-0.8	0.2	3.5	1.6
5	2.2	-3.1	-0.6	3.9	0.9	-1.4	-0.4	1.7	2.3	-3.2	-0.9	2.2

Table 7. Color difference comparison of samples according to CMC(l:c) i CIE76 systems for yellow color

Standard: 1 Plain weave 1/1, **Yellow color**												
	CIE76				**CMC(l:c)**				**CIEDE2000**			
Samples	**ΔL***	**ΔC***	**Δh**	**ΔE**	**ΔL*/Sl**	**ΔC*/Sc**	**Δh/Sh**	**ΔE**	**ΔL_{00}**	**ΔC^*_{00}**	**Δh_{00}**	**ΔE_{00}**
2	0.4	4.5	0.9	4.6	0.1	1.6	0.5	1.7	0.3	4.6	0.8	1.3
3	-0.1	3.2	-0.1	3.2	-0.1	1.1	-0.1	1.1	-0.1	3.2	-0.1	0.8
4	0.4	-1.7	1.3	2.2	0.1	-0.6	0.7	0.93	0.3	-1.6	-1.7	0.9
5	0.9	-1.3	1.8	2.3	0.3	-0.4	0.9	1.1	0.9	-1.2	0.9	1.2

For the green colour, CIE76 distributes the differences almost equally across lightness, chroma, and hue, resulting in relatively high ΔE values. CMC (l:c) reduces these values substantially because of its stronger weighting of lightness and suppression of hue contributions. The largest lightness difference is consistently observed in sample 3 (mixed panama) for all formulas, confirming that this structure produces the most perceptible deviation from the plain weave standard. Both CIE76 and CIEDE2000 highlight chroma and hue variations, whereas CMC downplays them. This illustrates the conceptual differences between the formulas: CMC was designed for the textile industry, optimised for practical tolerances and lightness-driven quality control, while CIEDE2000 was developed to approximate average visual perception across a broad set of psychophysical data. For the yellow colour, differences are almost exclusively chroma-driven. All three formulas detect this, with twill and mixed panama showing the strongest deviations. This is consistent with the spectral nature of yellow as a highly saturated colour at high lightness, where chroma variation dominates the perceptual difference. However, here again the formulas behave differently: CIE76 and CMC produce larger ΔE values, while CIEDE2000 moderates them through its perceptual scaling.

It should be emphasised that the values obtained from different formulas are not directly interchangeable, since each formula weights lightness, chroma, and hue differently. Moreover, recent research has questioned the reliability of CIEDE2000 for heterogeneous, structured surfaces, since the formula was developed and validated primarily on flat, homogeneous samples (Tsang, M. K., 2016; Ruili, H. et al., 2022). This raises the possibility that CMC, despite being an older formula, may remain more appropriate for fabrics with pronounced texture, while CIEDE2000 could underestimate perceptual differences in such cases. Our results, where CIEDE2000 consistently produces lower ΔE values compared to CIE76 and CMC, lend support to this view.

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Conclusions

The results of this study demonstrate that the surface texture of woven fabrics has a measurable impact on colour reproduction in digital printing. For the green colour, differences arise from a combination of lightness, chroma, and hue shifts, while for yellow the variation is dominated by chroma, reflecting its spectral characteristics as a highly saturated, high-lightness colour. Across all cases, ΔE values differ substantially between formulas: CIE76 generally yields higher values, CMC (l:c) reduces differences by emphasising lightness and suppressing hue contributions, and CIEDE2000 provides the lowest estimates due to its perceptual scaling. This confirms the non-interchangeability of formulas and highlights the importance of selecting an evaluation method appropriate to the material and application. Considering that CIEDE2000 was optimised for flat, homogeneous samples, its reliability on heterogeneous textile surfaces is limited, and CMC (l:c) remains a valuable tool for textile colour analysis. Ultimately, the study underscores that both the structural characteristics of fabrics and the choice of formula jointly determine the evaluation of colour differences, which must be critically considered in both research and industrial practice.

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Sustainable colour: a spectral perspective on natural vs synthetic dyes

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Abstract

This paper explores the emerging concept of "sustainable colour" – not only as a result of sustainable dyeing technologies, but as a perceptual and symbolic attribute of colour itself. Increasingly present in colour theory and design research, the term refers to colour palettes that evoke environmental harmony, low visual stimulation, and a connection to natural aesthetics. Particular attention is given to colour relationships inspired by nature and their association with ecological awareness. By integrating insights from textile chemistry and colour psychology, the paper positions sustainable colour as more than a surface quality. It becomes a medium for communicating ecological responsibility, creating emotional resonance between users and products or spaces, and achieving a balance between functionality, well-being, and aesthetic quality in contemporary design. The methodological focus of the paper presents a comparative analysis of colours obtained using natural dyes and their visually similar synthetic counterparts. Although visually comparable, the two types of samples differ significantly in their remission curves. Natural dyes, due to their complex chemical composition, tend to reflect more evenly across the visible spectrum, resulting in softer, less intense spectral curves. Synthetic dyes, in contrast, produce sharp reflection and absorption peaks, which more strongly stimulate visual perception. These findings support the hypothesis that, even when colourimetric coordinates appear similar, the perceptual and psychological response to naturally dyed textiles is often calmer, more soothing, and perceived as more "authentically sustainable." This subtle but measurable difference in spectral behaviour highlights the importance of integrating colour science with sustainable design strategies, reinforcing the idea that colour itself can act as a communicator of sustainability values.

Keywords: sustainable colour, remission, spectral analysis, natural dyes, synthetic dyes

Introduction

The concept of *sustainable colour* is gaining increasing relevance in both scientific and design discourse, yet it remains multifaceted and open to further exploration. On one level, sustainable colour refers to the use of dyes and pigments that have a reduced environmental impact, such as natural dyes or eco-certified synthetic alternatives. It includes considerations such as renewable resources, low-impact dyeing processes, and reduced chemical waste. However, beyond its material and technological aspects, the notion of sustainable colour becomes even more compelling when approached from a psychophysical and perceptual perspective. In this context, colour is not only a material outcome, but a communicative tool, one that contributes to how sustainability is perceived, interpreted, and emotionally experienced by viewers and users. Through its chromatic characteristics, spectral behaviour, and visual harmony, colour can evoke associations with nature, calmness, authenticity, and ecological balance. Colour palettes inspired by the natural world tend to elicit lower visual tension and are often intuitively read as "natural" or "sustainable," even in the absence of factual material data. This symbolic and affective dimension of colour plays a growing role in sustainable design, where aesthetics and environmental ethics are increasingly intertwined.

Despite its growing conceptual presence, scientific research explicitly addressing sustainable colour remains limited, especially in studies that examine how colour, as a result of dye chemistry and spectral behaviour, communicates sustainability in both a visual and psychological sense. This represents a research gap that opens up the need for interdisciplinary research that investigates how

the chemical structure of dyes affects the way colour conveys the context of sustainability through its psychophysical, emotional and cognitive impact on the viewer.
The present paper combines a brief overview of relevant literature with original experimental work. The experimental section focuses on a comparative spectrophotometric analysis of visually similar colours obtained using natural and synthetic dyes. These dyes differ not only in origin, but also in chemical composition: synthetic dyes are chemically pure substances produced under controlled laboratory conditions, while natural dyes are complex mixtures of related compounds derived from plant-based sources. By comparing two visually matched colours, one dyed with a synthetic dye and the other with a natural equivalent, it was analysed how each substance constructs its remission curve and how these curves differ in terms of spectral shape, smoothness, and intensity. The aim is to investigate whether and how these spectral differences, arising from dyestuff constitution, correlate with the psychological perception of sustainability in colour. This approach, linking material structure with perceptual response, offers a contribution to the emerging discourse on sustainable colour as both a technical and communicative phenomenon in contemporary design.

Colour, Sustainability and Perception: An Overview of the Literature
A considerable number of studies in recent literature investigate sustainable colour primarily through the application and improvement of eco-friendly dyes, whether natural or low-impact synthetic alternatives. These studies emphasize the extraction, modification, and dyeing performance of natural colourants, as well as their ecological advantages in reducing chemical load and supporting circular textile strategies.

Che and Yang (2022) provide a comprehensive review, concluding that while no natural dye is entirely sustainable, many offer significant ecological, aesthetic, and functional benefits that make them viable alternatives to synthetic dyes in selected textile applications. Their analysis identifies cotton and wool as the most widely explored substrates, while also acknowledging recent efforts toward integrating natural dyes with regenerated and synthetic fibres. Moreover, they highlight the multifunctionality of many natural dyes, such as antibacterial, UV-protective, antioxidant, and deodorizing effects, and point to bio-mordanting and technologies like plasma or gamma irradiation as promising directions for improving colour performance and sustainability. A growing number of studies explore the interest in natural dyeing as a promising strategy for reducing the environmental burden of synthetic dye use in textiles. According to Shahid-Ul-Islam and Sun (2017), Sutrisna et al. (2020), Grifoni et al. (2011) and Shahid et al. (2013), natural dyes are valued not only for their biodegradability and health safety, but also for their soft and elegant aesthetic qualities. More recent efforts (e.g., Nambela et al., 2020; Atav et al., 2020) focus on improving colour yield and fastness through optimized extraction and dyeing techniques, while also considering the functional properties of natural compounds and their impact on wastewater quality.

Nambela et al. (2020), in their research, pointed out that although natural colourants are biodegradable, locally available, and offer functional properties such as antimicrobial activity, they often suffer from poor fastness, low affinity, and low yield. Their work stresses the need for technological advancements in dye extraction, the use of greener mordants, and the exploration of renewable biomass sources, such as cashew nut shell liquid (CNSL), for the green synthesis of future colourants. In addition, recent research increasingly explores *sustainable colour* as a communicative and perceptual phenomenon, examining how colour itself, regardless of the dye source, can evoke and convey sustainability values. Within this perspective, colour is not only a physical property of dyed material, but a semantic and affective signal which influence attitudes, emotional responses, and environmentally conscious behaviour. Several authors have highlighted how colour palettes inspired

by nature or associated with harmony, calmness, and earth shades are intuitively perceived as "sustainable," even when produced with conventional dyeing methods.
Labrecque et al. (2013), Lim et al. (2020), and Sundar & Kellaris (2017) investigate the role of colours such as green, blue, and brown in sustainable marketing and branding. Their findings show that consumers intuitively associate these colours with sustainability values and with products perceived to have a lower environmental impact. Kunz et al. (2020) and Xiao et al. (2021) conducted studies focusing on colour saturation as a key factor in shaping perception, specifically, that lower saturation (i.e., higher levels of grey) can lead to a higher perceived level of sustainability in products.

Pichierri and Pino (2022) conducted an extensive series of five experimental studies that confirmed consumers' unconscious tendency to associate low colour saturation with a product's gentler impact on the environment. Their research investigated low-saturated shades of green, red, yellow, and orange, and demonstrated that such colours, regardless of hue, tend to enhance the perception of environmental friendliness. In addition to contributing empirical evidence to the growing literature on sustainable colour perception, their findings offer practical implications for sustainability-oriented companies. Specifically, the results suggest that using low-saturation colours can enhance a product's eco-friendly image and indirectly strengthen consumers' trust in a brand's environmental commitment. In contrast to this focus on saturation, other researchers have examined how colour hue affects perception. Mehta and Zhu (2009) and Hagtvedt and Adam Brasel (2017) researched how different hues influence consumer responses, brand positioning, and behavioural outcomes. These studies indicate that hues such as green or blue are commonly associated with trust, calmness, and nature, which may also reinforce perceptions of sustainability, albeit through different chromatic pathways than those explored in saturation-focused research.

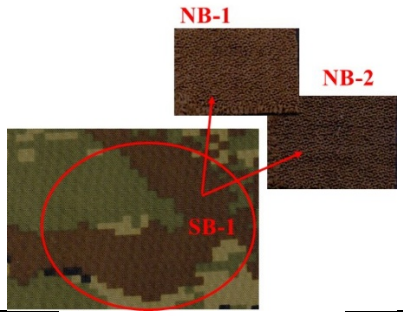
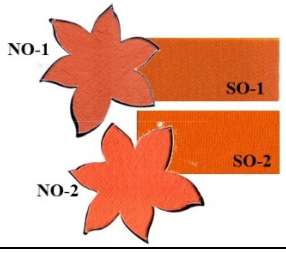
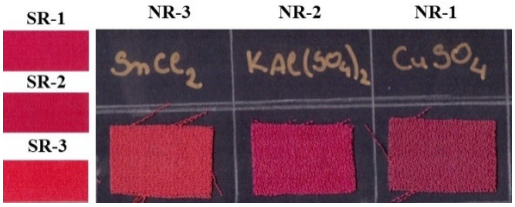
As highlighted in the literature review, research on sustainable colour has primarily focused on perceptual aspects such as hue and saturation, attributes known to influence consumer associations with nature, calmness, and ecological values. It is well established that low saturated or earthly colours are often interpreted as "eco-friendly", particularly when they resemble colours commonly found in natural environments. However, the aim was to move beyond symbolic associations and bring attention to the optical structure of colour itself. The core hypothesis is that it is not only *which* colour is used that matters in communicating sustainability, but *how* that colour is built, chemically and optically. In other words, a soft, low-saturation hues may suggest sustainability to the observer, but it may not produce the same psycho-emotional effect if it is generated with a chemically pure synthetic dye versus a structurally complex natural dye. So, in this paper a part of the study that analyses colours from the brown, orange, and red regions of the spectrum is presented. Visually matched samples, prepared by both natural and synthetic colourants, were used. The spectrophotometric measurement was performed in order to define the spectral characteristic of these samples, aiming in presenting the differences in light reflectance. Natural dyes, due to their heterogeneous molecular composition, tend to reflect light more diffusely, creating smooth and evenly distributed remission curves. Synthetic dyes, in contrast, often show sharper, more selective absorption and reflection due to their narrow-band chemical structure. These optical differences may not be so visible to the eye, yet they may contribute to a different visual impression, even when the colours appear chromatically similar. This measurable distinction suggests that colour in sustainable design should not be approached solely as a symbolic visual cue, but also as an optical and material phenomenon. The findings propose that remission-based spectral behaviour may be important factor in how colour communicates ecological integrity.

The results are presented through graphical remission curves and tabular representations of CIE L**C**h° colour parameters.

Experimental (Materials and Methods)

In this study, samples dyed with both natural and synthetic dyestuffs were analysed. Table 1 presents an overview of the selected colour shades, including the type of the dyestuff (synthetic or natural), the colour lable from the internal database, sample labels used in results, and photographic images of each dyed material.

Tab. 1 – Description of materials used in this article

COLOR	DYESTUFF	NAME	LABEL	PICTURE
Brown	Synthetic	Military	SB-1	
	Natural	Green tea leaves	NB-1	
		Aider bark Cu	NB-2	
Orange	Synthetic	Bemacid N Orange N-B 0.50%	SO-1	
		Bemacid Orange N-GB 0.55%	SO-2	
	Natural	Madder pH 4 without mordant	NO-1	
		Madder pH 4 Al	NO-2	
Red	Synthetic	Bemacid Rot 3GP 1.25%	SR-1	
		Bemacid Rot B 1.5%	SR-2	
		Bemacid Rot 3G 0.5%	SR-3	
	Natural	Cochineal Cu SO_4	NR-1	
		Cochineal $KAl(SO_4)_2$	NR-2	
		Cochineal $SnCl_2$	NR-3	

Coloristic analysis on selected materials were performed using a Datacolor 850 spectrophotometer under daylight (mark D65), standard observer 8° at a wavelength of 360-700 nm. Measurements were taken at random locations on the samples using the "Measure until Tolerance" command. The obtained results are presented as CIE L*C*h° parameters and remission curves. Remission, R [%], of the dyed samples was measured according to ISO 105-J01:1997, EN ISO 105-J01:1999 *Textiles – Tests for colour fastness – Part J01: General principles for measurement of surface colour*.

Results and discussion

Remision curves of selected samples dyed with synthetic dyes and samples dyed with natural dyes are presented at Fig. 1 for brown sample, at Fig. 2a and Fig. 2b for orange samples and Fig. 3a, 3b and 3c for red samples.

The aim of this part of the study was to objectively examine, using spectrophotometric methods, the differences in optical characteristics between colours obtained with natural and synthetic dyestuffs, even when they appear visually similar. While the spectral behaviour of a dye is dictated by its chemical structure, this analysis focuses on the resulting colour as a measurable phenomenon, and explores whether the remission profile of natural dyes helps explain their aesthetic appeal and association with sustainability. Specifically, this study asks whether colours produced with natural dyes, despite appearing similar in hue and saturation, differ in their spectral smoothness, balance, and

complexity, and whether such differences could contribute to the human eye's preference for these colours. The goal is not to generalise human response, but to open the question of whether the remission characteristics of natural dyes may provide a visual softness or harmonic light distribution that makes them more pleasing, more relatable to the natural environment, and potentially more effective in communicating sustainable values. The remission curve describes how a coloured surface reflects light across the visible spectrum and offers valuable insight into the physical nature of colour. In the case of synthetic dyes, the remission curves typically show sharp and selective peaks, corresponding to strong absorption in specific wavelength regions, which results from their chemically pure and uniform composition. Natural dyes, by contrast, tend to produce broader and smoother remission curves. This is due to their heterogeneous chemical composition, which leads to less selective absorption and a more diffuse reflection of light across multiple wavelengths. Even when two colours appear visually similar, these spectral differences may contribute to the softer and more balanced appearance often associated with naturally dyed materials, and may help explain why such colours are perceived as more harmonious and sustainable.

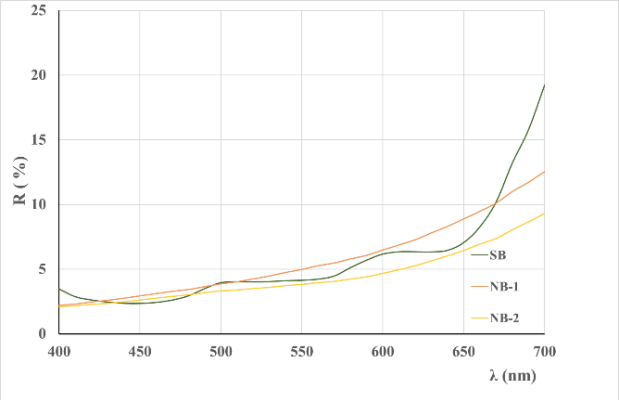


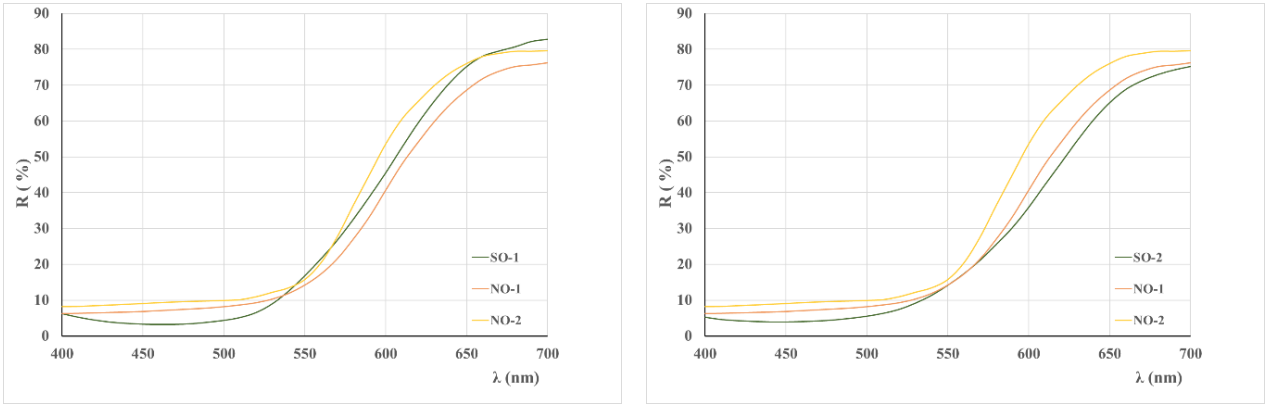
Fig. 1 Remission curves of brown samples

Figure 1 shows remission curves for brown colours obtained with synthetic and natural dyes. The sample labels correspond to those listed in Table 1, where NB-1 and NB-2 represent colours dyed with natural dyes, while SB refers to the synthetic counterpart. The types of fibres and chemical classes of dyes are intentionally not mentioned, as the primary focus on colour as a perceptual phenomenon arising from the interaction between light and dyestuff, natural or synthetic.

In the graph, the synthetic dye (SB) exhibits a more pronounced and defined spectral behaviour, with sharper reflectance peaks and curve that suggest mixed dyestuff, even in the case of this achromatic brown colour. This suggests a more selective light interaction and a narrower band of reflectance, characteristic of chemically pure and compositionally homogeneous synthetic dyes. In contrast, the remission curves of the natural dyes (NB-1 and NB-2) are smoother, with less changes and more gradual reflectance increase toward longer wavelengths. This behaviour likely stems from the chemically complex nature of natural dyes, which are composed of multiple colour-bearing compounds, each contributing differently to the overall spectral response. Even though all three samples are visually similar in colour, the underlying spectral differences suggest that the perceptual experience, especially in terms of softness and visual comfort, may be affected by these physical properties. Such findings support the hypothesis that natural dyes create subtler, less aggressive optical signals, potentially contributing to their association with "sustainable" or "natural-feeling" colours.

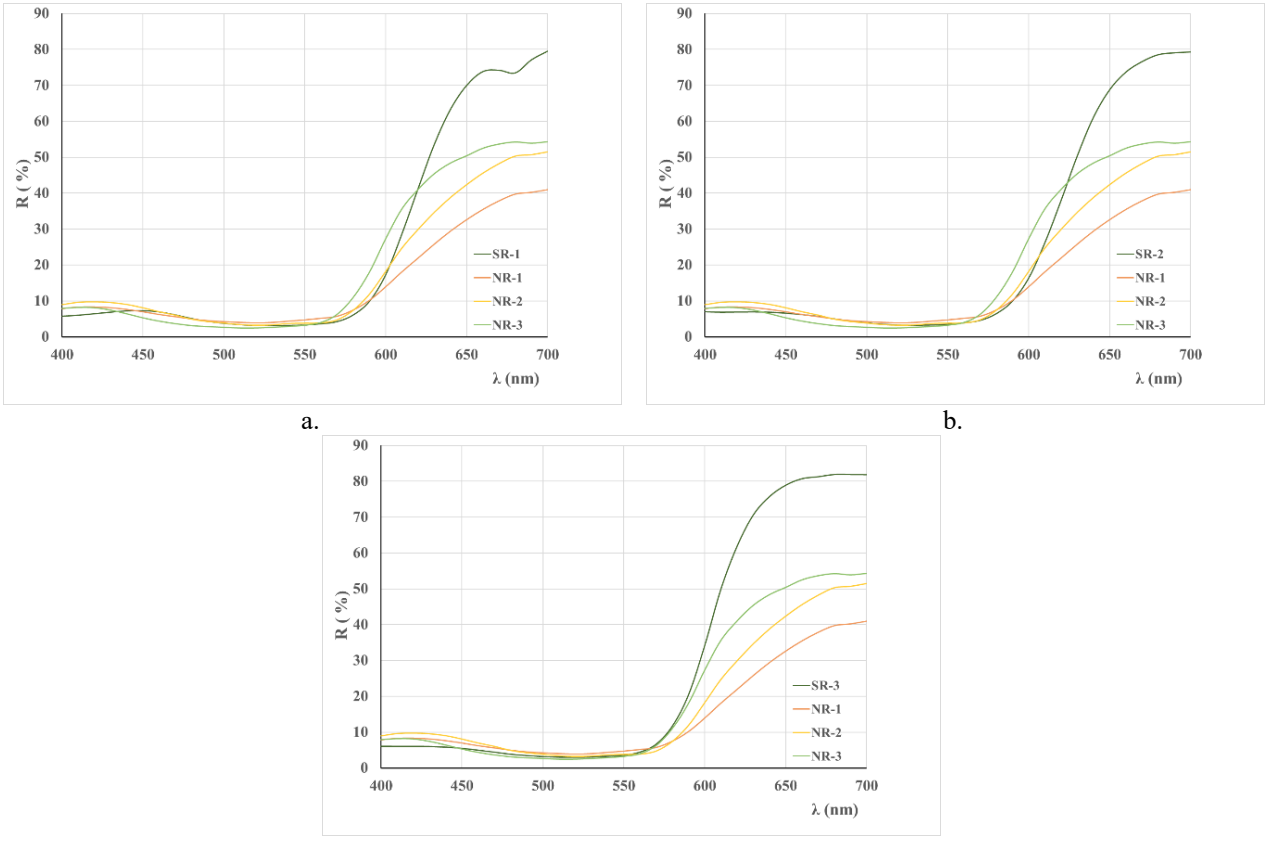
Figures 2 represents the remission behaviour of orange samples. Here, both natural and synthetic dye samples show highly similar curve shapes and overlapping reflection behaviour. This suggests that,

for this particular hue, the remission characteristics of natural dyes can closely mimic those of synthetic ones, at least under selected conditions. The similarity may result from a comparable combination of absorption and reflection in the orange part of the spectrum, or a closer alignment in chromophore interaction within the same spectral region. This result raises new questions about the limits of differentiation based purely on spectral smoothness and underlines the need for further exploration across other tones and substrates.



a. b.

Fig. 2 Remission curves of orange samples compared with samples dyed with natural dyes: a. SO-1, b. SO-2



a. b.

c.

Fig. 3 Remission curves of red samples compared with samples dyed with natural dyes: a. SR-1, b. SR-2, c. SR-3

Figures 3 presents the remission curves for red samples. In all three comparisons, the synthetic dye samples (SR-1, SR-2, SR-3) show significantly sharper, steeper curves with high reflectance beyond 600 nm, while the natural dye samples (NR-1, NR-2, NR-3) display more gradual increases. The

synthetic dyes reflect more intensely in the red region, indicating strong chromatic purity and narrow absorption bands, consistent with their single-compound chemical structure. Natural dyes, in contrast, reflect more diffusely and broadly, producing curves that suggest softer transitions and lower visual stimulation. These results reinforce the hypothesis that remission curves, shaped by the molecular structure of the dyestuff, may provide a measurable basis for the perceptual difference often attributed to natural colourants. Even when colours appear visually similar, their spectral profiles can differ in subtle yet meaningful ways. Natural dyes appear to reflect light in a more evenly distributed manner across the spectrum, potentially contributing to the perception of gentler, more harmonious colour experiences that are often associated with sustainability and natural aesthetics.
The results of the objective colour evaluation based on spectrophotometric measurements of selected samples and their differences are presented in Table 2. Differences between the samples dyed with synthetic dyes and samples dyed with natural dyes are shown in Tables 3, 4 and 5.

Tab. 2 – Colour parameters of selected brown, orange and red samples dyed with synthetic and natural dyes

Colour	Sample	*L**	*C**	*h*°
Brown	SB	25.48	13.39	67.31
	NB-1	27.23	13.69	64.85
	NB-2	23.62	9.31	65.22
Orange	SO-1	54.97	69.77	53.69
	SO-2	51.08	58.60	51.65
	NO-1	53.36	52.70	44.53
	NO-2	58.32	55.83	43.02
Red	SR-1	37.80	52.76	13.30
	SR-2	37.47	50.91	14.42
	SR-3	44.38	65.65	26.54
	NR-1	34.01	33.02	8.34
	NR-2	35.59	43.15	5.65
	NR-3	39.18	53.87	21.38

To complement the remission curve analysis, Table 2 presents the CIELAB values for all compared samples, focusing on three key colour attributes: lightness (L*), chroma (C*), and hue angle (h°). These parameters were included to objectively confirm that the selected colour pairs, natural and synthetic, are not only similar in visual perception, but also quantitatively comparable in their colourimetric coordinates. The L* values indicate that the pairs fall within a similar lightness range, while the chroma (C*) values confirm comparable colour saturation. Likewise, the hue angles (h°) demonstrate that all samples belong to the same colour family (brown, orange, or red). By ensuring that the compared samples share similar L*, C*, and h° values, the study highlight that even spectrally similar colours may differ in how they reflect light across the visible spectrum.

Conclusion

Although no perceptual testing was conducted in this study, the remission characteristics observed offer a possible explanation for the frequent association of natural dyes with softness, balance, and emotional comfort. The smoother, more continuous reflection across the visible spectrum, typical of naturally dyed samples, may result in lower visual stimulation and a more harmonious sensory experience for the observer. By contrast, synthetic dyes, with their sharper spectral profiles, may more strongly activate specific photoreceptor responses, potentially contributing to a more intense but less subtle visual effect. This suggests that the optical signature of a colour, shaped by the chemical nature of the dyestuff, may influence the way it is perceived, beyond what chromatic coordinates alone can describe. Such differences, although not consciously perceived, could underlie the growing aesthetic and emotional preference for natural dyes in sustainable design contexts.

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Developing a framework to study color variations in ancient ink: Preliminary analysis

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Abstract

The conservation of ancient written documents is critical for preserving human historical, intellectual, and artistic heritage. To this end, it is essential to guarantee the stability of ancient ink on paper across time. This is highly dependent on both chemical composition and conservation conditions. This study reports the preliminary analyses conducted within the scope of Spoke 5 – CHANGES project, aiming to define an experimental procedure for analyzing chromatic variations over time in ancient inked manuscripts. Six different ink compositions were synthesized by differently combining historically accurate components: ferrous sulfate, gallic acid, Arabic gum, coal, and linseed oil. The inks prepared were applied in liquid form to Whatman 1 paper supports. When dried, spectral reflectance measurements were performed weekly from the 3rd of March to the 5th of May 2025. CIELAB colorimetric coordinates were calculated and variations in lightness (L*), hue (h_{ab}), and chroma (C^*_{ab}) were analysed. Results show that samples generally became darker (L* decreases) and less saturated (C^*_{ab} values decrease), with a* values decreasing and b* ones increasing over time. Moreover, significant variations in colorimetric coordinates occurred between the first and second measurements (ΔE^*_{ab} values up to 2.82); then, variations were smaller (ΔE^*_{ab} values lower than 1) starting from the third measurement on. Based on the results obtained, suggestions for improving the analysis procedure are derived.

Keywords: ink ageing, ancient manuscripts conservation, ink chromatic variations, CIE L*a*b* color space, non-invasive analysis for paper documents.

Introduction

Ancient written documents offer insights into writing practices, artistic techniques, traditions, and technologies of the past. Therefore, their conservation is critical for preserving human historical, intellectual, and artistic heritage. To this aim, it is essential to guarantee the stability of ancient ink on paper across time and slow down its degradation, which strictly depends on its chemical composition.

Inks are defined as liquid or semi-liquid substances used for writing. Historically, ancient scribes developed inks using carbon black dispersed in various liquid mediums (Mitchell and Hepworth, 1904). Later, the medieval era saw the advent of iron-gall ink that was produced through a chemical reaction involving vitriol (ferrous sulfate) and gallic acid (a compound obtained from the boiling of gall nuts and hydrolysis of tannins) (Edwards *et al.*, 2022). Arabic gum was frequently incorporated to improve the ink's application properties (Caterino *et al.*, 2023). Despite the extensive literature on these inks, there is a distinct lack of research on inks intentionally created by mixing charcoal with tannin extracts or iron-gall ink (Aceto *et al.*, 2008; Bicchieri *et al.*, 2008). The goal of these studies is to understand how the presence of both carbon and iron-gall ink might influence established degradation mechanisms of inks and paper or potentially give rise to novel degradation pathways.

In any case, the stability of ancient inks is highly dependent on environmental factors and conservation conditions as well. Light, air temperature, and humidity can influence the degradation processes of both paper and ink components. For example, Confortin et al. (Confortin *et al.*, 2010) studied the photofading of crystal violet, one of the earliest synthetic dyes used as an ink component on different paper substrates, exposing them to both UV-Visible and Visible radiation. They found that the spectral distribution of the incident radiation and the presence of an ink additive, as Arabic gum, played a role in the color change and observed a strong discoloration also under Visible radiation only. Moreover, Liu et al. (Liu *et al.*, 2022) studied the discoloration process of iron gall ink due to oxygen, relative humidity (RH), and light exposure. They found that oxygen, RH, and their interaction had a stronger effect on the discoloration of iron gall ink compared to light levels. They studied the spectral sensitivity of the inks, exposing them to narrowband radiation centered at three different wavelengths: 450 nm, 525 nm, and 625 nm, with varying oxygen and RH levels, finding that for 450 nm the degradation was 3 times and 10 times faster than for 525 nm and 625 nm, respectively.

Based on these premises, it is clear that a comprehensive understanding of ink chemistry and degradation pathways associated with microclimatic conditions turns out to be essential to define effective conservation strategies.

The research presented here is part of the activities carried out within the scope of the CHANGES - SPOKE 5 project financed by the "PNRR Missione 4 Componente 2 Investimento 1.3 – Next Generation EU". The overall goal of the project is to develop advanced scientific methods for cultural heritage applications, characterizing artifacts, understanding their degradation mechanisms, and promoting conservation practices that ensure their long-term protection. In this context, one of the activities involves analyzing the degradation mechanisms of different compositions of ancient ink applied to paper, due both to the aging process itself and to different microclimatic and lighting conditions. The considered inks are obtained by mixing historically accurate components used in different ages, including also charcoal, the effect of which has been poorly investigated, as mentioned before. To study the degradation mechanisms, it is necessary to prepare specific paper samples representative of ancient documents and expose them to an artificial aging process in a climate chamber or different irradiation conditions for a prolonged period. Then, the colorimetric coordinates of the samples can be measured over time to monitor potential alterations. To set up this experiment, preliminary analyses are necessary. The results are presented in this article.

Two main problems had to be faced during these preliminary tests. First, considering that a standard spectrophotometer with a 1 cm diameter aperture would be used to measure the colorimetric coordinates, it was necessary to apply the ink to the paper in such a way as to ensure at least one uniform spot the same size as the instrument's viewfinder. This was not an easy task, since even if the application procedure was the same, the inks spread on the paper in different ways, depending on their composition. Furthermore, it was observed that after being applied to the paper, the inks showed chromatic alterations visible to the naked eye and then appeared to stabilize. It was therefore necessary to understand how long this "stabilization" took before exposing the samples to artificial aging or radiation. Therefore, this study presents the procedure adopted for preparing the inks, highlighting the challenges associated with both preparation and application to paper, the procedure for measuring the colorimetric coordinates of the inks, and the results of the measurements performed to quantify the stabilization period.

Method

1. Preparation and application on paper of the inks

This work involved the synthesis of six model inks composition by using and differently combine historically accurate components: ferrous sulfate and gallic acid (sample 1), ferrous sulfate, gallic

acid and coal (sample 2), ferrous sulfate, gallic acid and Arabic gum (sample 3), ferrous sulfate, coal and linseed oil (sample 4), ferrous sulfate, gallic acid, Arabic gum, and linseed oil (sample 5), ferrous sulfate, gallic acid, coal, Arabic gum and linseed oil (sample 6) (Mitchell and Hepworth, 1904; Lee *et al.*, 2006; Ferretti *et al.*, 2022). Once prepared, these liquid inks were applied to Whatman 1 paper supports, cut into squared shapes of 4 cm^2, using a Gilson pipette. Several depositions were performed until 100 µL was achieved. Following the application, the samples were dried at room temperature. The time required for drying varied from 1 to 3 days. Notably, ink formulated with oil (4, 5, 6) required a somewhat longer drying period due to the inherent evaporation properties of the oily components. Finally, the samples showed distinct morphologies and colors, due to dilution and the nature of the chemicals used, as can be seen in Fig. 1.

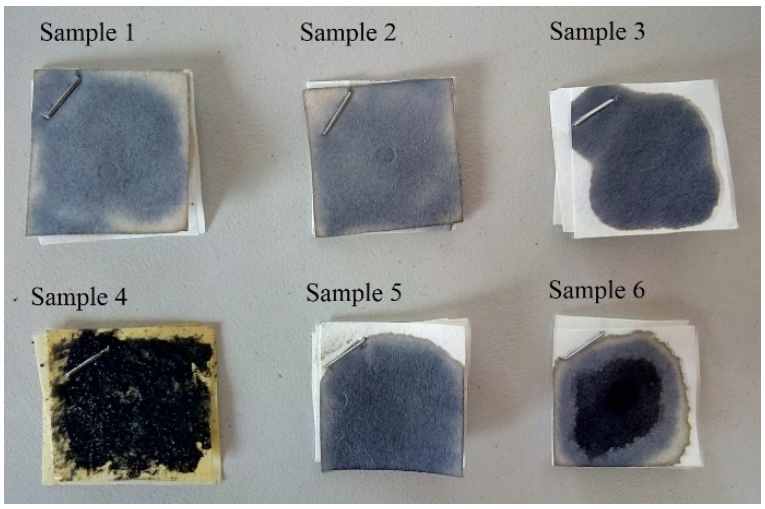

Fig. 1 – Photos of the six samples

2. Spectral reflectance measurements

Spectral reflectance measurements were performed by means of a Konica Minolta CM-2600d spectrophotometer, directly providing L*, a*, b*, h_{ab}, and C^*_{ab} values under D65 with a 10° observer. For each sample, measurements were performed by pointing the instrument towards the center of each square paper. To align the instrument to the central point and be sure to repeat the measurements always in the same way over time, masks (like stencils) of the same dimensions of the samples were prepared (Fig. 2). They were made in black cardboard and were pierced to obtain a central hole of the same diameter (1 cm) of the viewfinder of the instrument. To perform the measurements, the mask overlapped the samples, and the instrument was positioned such that the aperture hole and the hole of the black cardboard coincided. In previous work (Bellia *et al.*, 2023) it was underlined that Whatman 1 paper is slightly transparent and transmits part of the incident radiation. For this reason, two more layers of Whatman 1 paper were cut and put below each sample. Moreover, to be sure that this expedient was sufficient to make the samples opaque, for each sample, measurements were repeated locating the three layers of paper on two different backgrounds, i.e., black and orange NCS samples (NCS S9000N and NCS S0585-Y50R). The results obtained were compared. If the differences were null, the samples would be completely opaque.

For each sample, measurements were repeated each week from the 3rd of March to the 5th of May 2025. Between consecutive measurements, samples were stored in the dark at room temperature. CIELAB colorimetric coordinates were calculated, and variations in lightness (L*), hue (h_{ab}), and chroma (C^*_{ab}) were analyzed. Moreover, ΔE^*_{ab} values were calculated by comparing the results obtained each week against those referred to the previous one.

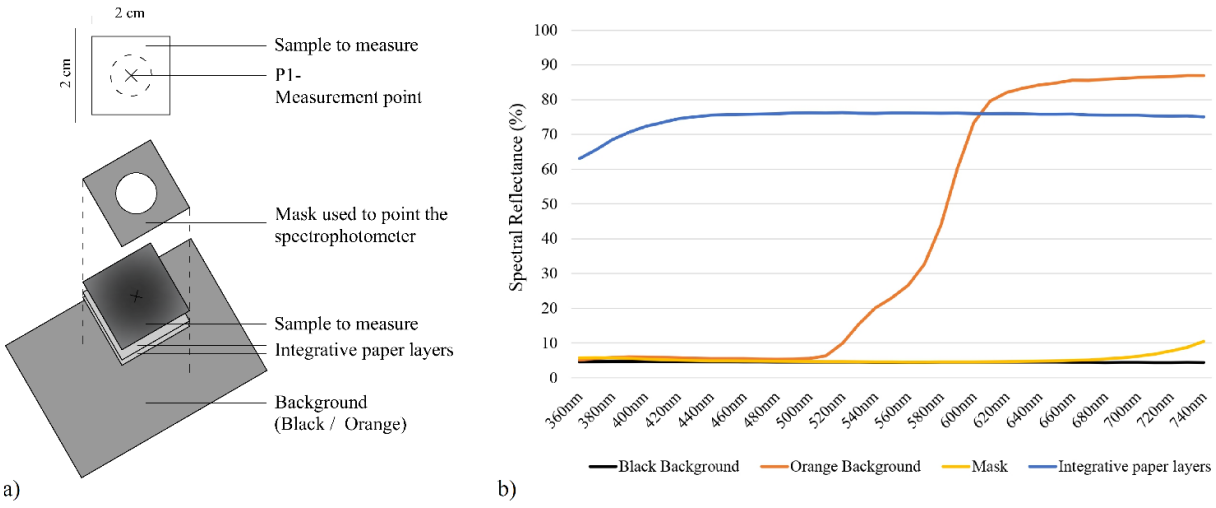

Fig. 2 – Scheme of the samples' setting for measurements (a) and materials' spectral reflectance (b)

Results

Fig. 3 reports the samples' colorimetric coordinates measured on the black and orange backgrounds at the beginning and the end of the observation period. It can be observed that for samples 1, 2, 3, and 5, both at the beginning and at the end of the experiment, the coordinates are the same for both backgrounds. On the contrary, for samples 4 and 6, they differ. In detail, for these samples, the a* values are higher when the orange background is used; this is particularly evident at both the beginning and at the end of the experiment for sample 4, and only at the end for sample 6. Overall, it can be assumed that for all the samples, except for 4 and 6, the measurements are not affected by the background, indicating the samples are sufficiently opaque. On the contrary, the transparency of samples 4 and 6 may be due to the fact that they are not uniformly applied on the paper, as can be seen from Fig. 1. In turn, this may depend on their composition. Specifically, it can be noticed that sample 4 appeared grainy, and some charcoal particles detached from the paper over time. Moreover, sample 6 appeared not uniformly distributed on the paper, and the differences between the spots became more evident over time.

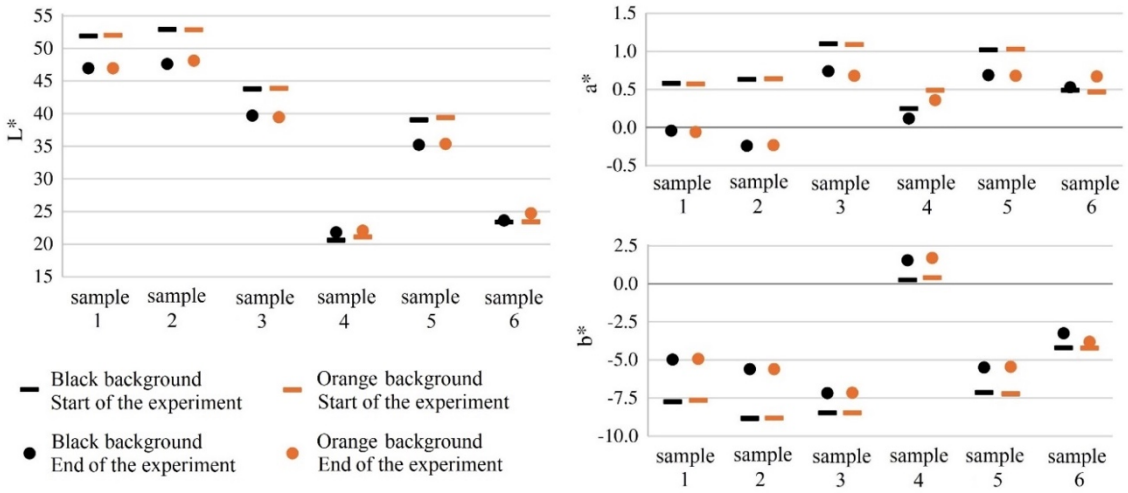

Fig. 3 – Samples' colorimetric coordinates measured on the black (in black) and orange (in orange) backgrounds at the beginning (dashes) and end (dots) of the observation period

Consequently, it was decided to present only the results related to the black background. Indeed, as suggested in (Bellia *et al.*, 2023), the use of an opaque black, almost non-reflective base reduces the risk that radiation reflected by the background and transmitted through the paper affects the measurements.

Fig. 4 reports the L*, a*, and b* values measured throughout the observation period. On each graph, labels indicate the time of the measure, e.g., t0 corresponds to measurements taken on the 3rd of March (start of the experiment), t9 corresponds to measurements taken on the 5th of May (end of the experiment).

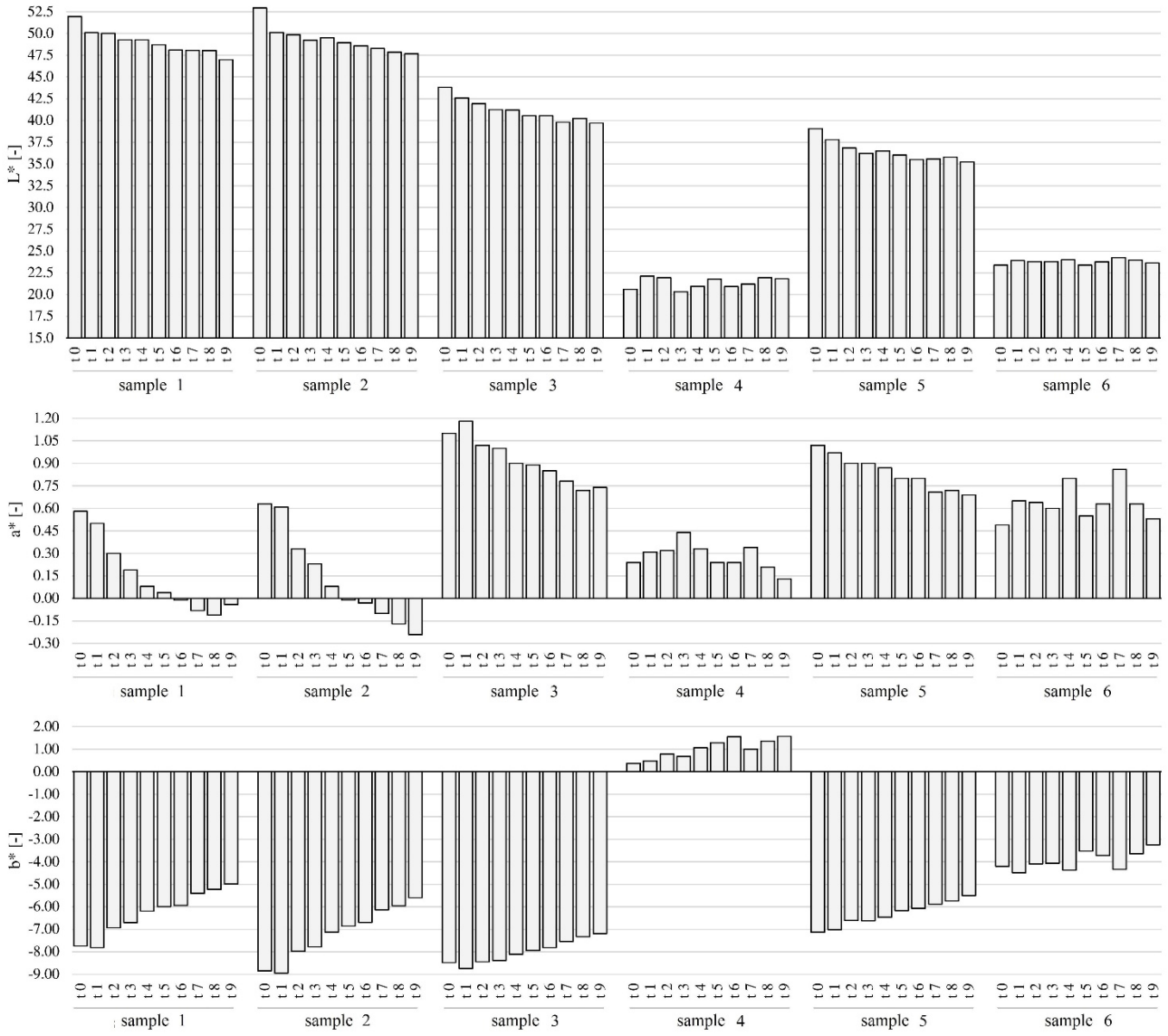

Fig. 4 – Samples' L*, a*, and b* values measured over the observation period; data are grouped for sample. Labels t0 to t9 indicate the time of the measure

At the beginning of the observation period, samples show different characteristics, with L* values ranging from 53 (sample 2) to 21 (sample 4), a* values ranging from 0.25 (sample 4) to 1.10 (sample 3), and b* values ranging from -8.84 (sample 2) to 0.38 (sample 4). In more detail, samples 1, 2, 3, 5, and 6 showed positive and negative a* and b* values, respectively, hence falling within the red to

blue quadrant, while sample 4 showed positive a* and b* values, hence falling within the red to yellow quadrant. As time passes, variations in all the colorimetric coordinates occur for all samples. Overall, they generally become darker (L* decreases), a* values decrease, and b* values increase. However, some differences can be noticed. Indeed, the described trends are observed for all measurements on time varying for samples 1, 2, 3, and 5. On the contrary, sample 4 shows alternately increasing and decreasing L* and a* values, while b* values generally increase. Sample 6 shows alternately increasing and decreasing a* and b* values, while L* values appear almost constant over time. Samples' colorimetric attributes can also be expressed in terms of hue and chroma reported in Fig. 5. It can be seen that, except for sample 4, the hue almost remains the same as time passes, whereas variations in chroma occur. In particular, samples 1, 2, 3, and 5 become less saturated (C^*_{ab} values decrease) and sample 4 becomes more saturated (C^*_{ab} values increase) over time. Sample 6 shows an alternately increasing and decreasing C^*_{ab} values.

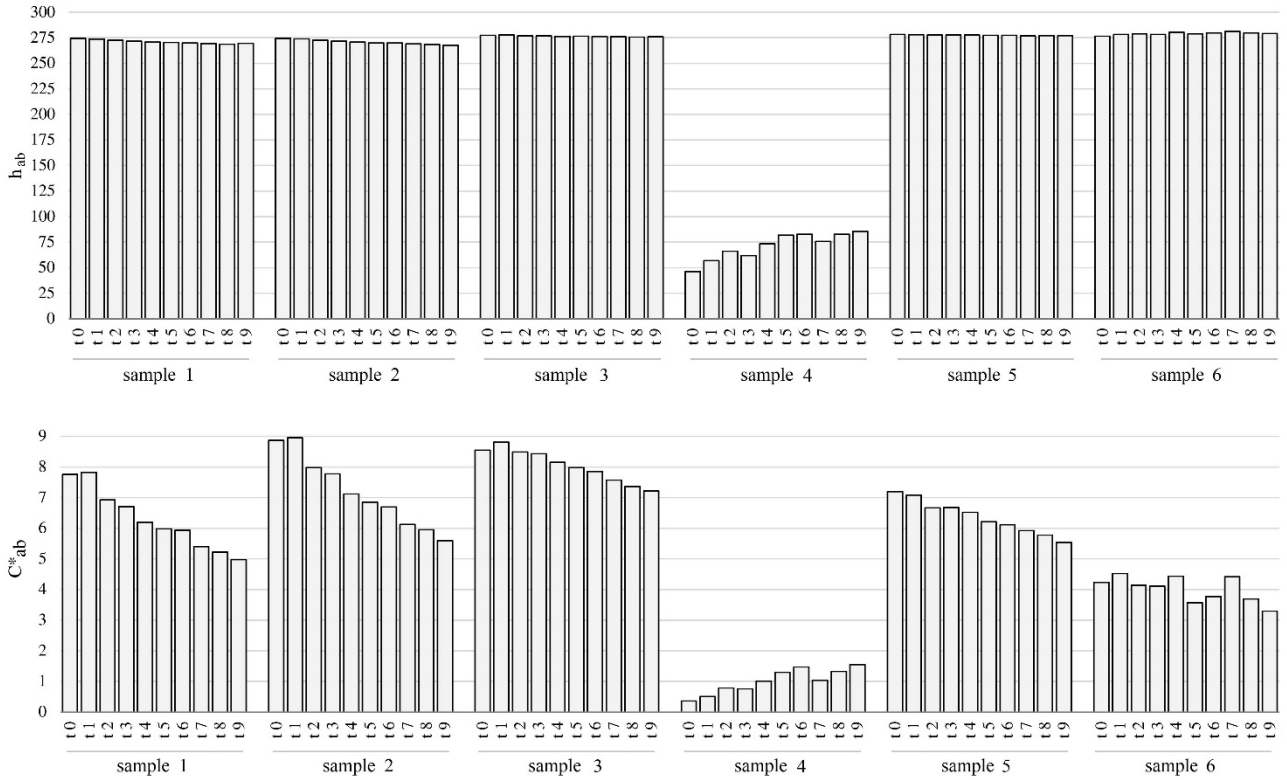

Fig. 5 – Samples' h_{ab} and C^*_{ab} values measured over the observation period; data are grouped for sample. Labels t0 to t9 indicate the time of the measure

Fig. 6 reports the ΔE^*_{ab} values obtained throughout the observation period. As described in the method, differences are calculated week by week. For example, label t2 – t1 in the graph indicates the comparison of colorimetric attributes measured at the end of the second week (t2) against those registered after one week (t1).

Overall, for samples 1, 2, 3, and 5, variations generally decrease over time. In particular, considering t1 – t0 differences, ΔE^*_{ab} values are equal to 1.85, 2.82, 1.27, and 1.27 for samples 1, 2, 3, and 5, respectively. Hence, starting from the third week (see t3 - t2), ΔE^*_{ab} values become lower than 0.8. The only exception is observed at the end of the experiment for sample 1. Again, samples 4 and 6 show alternately increasing and decreasing ΔE^*_{ab} values over time.

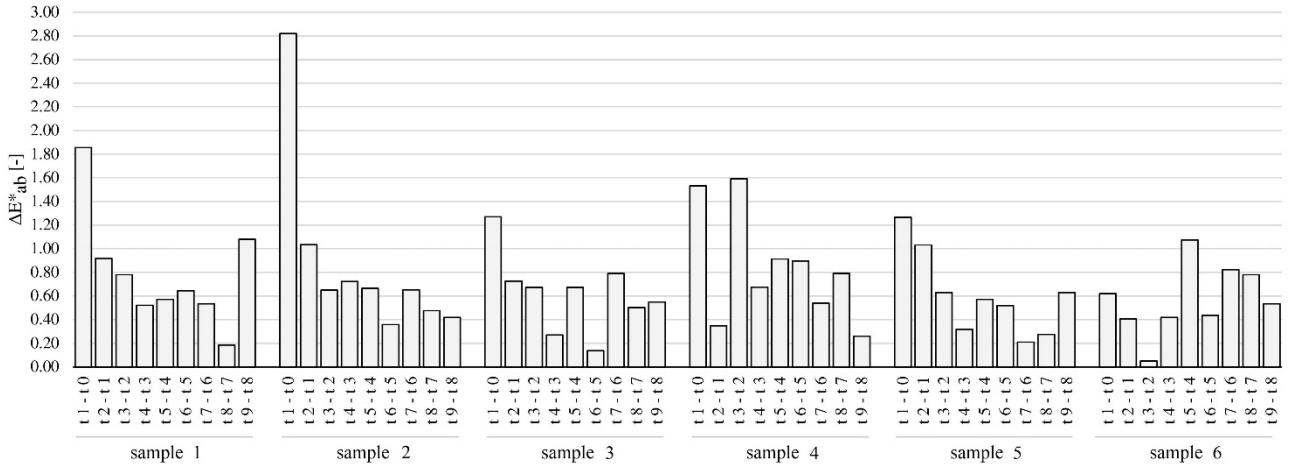

Fig. 6 – Samples' ΔE^*_{ab} over the observation period

Discussion and conclusion

This study presented the results of preliminary analyses carried out to set up an experiment aimed at analyzing the degradation mechanisms of different compositions of ancient ink applied to paper, as part of the activities carried out within the scope of the CHANGES - SPOKE 5 project. In particular, this study focused on the difficulties and challenges faced during the preparation of the samples and the execution of the colorimetric measurements. For the future steps of the research, the preparation and application of final procedures of the inks and the protocol for measurements will be built upon these preliminary findings.

First, it was observed that in some cases, measurements were affected by the background. This occurred for samples 4 and 6, for which the ink distribution was not uniform on paper. This suggests that for samples 1, 2, 3, and 5 the opacity was due to the homogeneous ink application. For this reason, for future studies, it will be necessary to improve the inks' preparation and application procedures. Specifically, it has been decided to finely ground the charcoal using a mortar to achieve a more homogeneous sample composition. Moreover, the volume of the sample deposited on the paper will be adjusted to a total of 300 µL, with an application of 100 µL at a time. Between every deposition, the sample will be allowed to dry to ensure better coverage. Additionally, it has been decided to remove the linseed oil, since oil and water phases create an unstable emulsion that breaks, causing the re-aggregation of similar molecules, especially for inks containing the charcoal particles. Moreover, it could also be useful to use a higher number of paper layers to achieve more opacity.

As regards the chromatic variations over time, results indicated that most samples (1, 2, 3, and 5) showed a general trend towards becoming darker (decreasing L*) and less saturated (decreasing C^*_{ab}), with decreasing a* values and increasing b* values over the observation period. Hence, chromatic alterations in the inks occurred following their application, indicating the need for a period of stabilization before exposing them to artificial aging or radiation. However, the decreasing ΔE^*_{ab} values observed after the third week (becoming lower than 0.8) suggested that a stabilization period of approximately two to three weeks could be sufficient.

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Color and Lighting

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Enhancing the neutral: white surfaces and luminous quality in the historic spaces of Villa Argentina

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Abstract

The USI Academy of Architecture in Mendrisio is housed in Villa Argentina, which offers a unique setting for investigating how natural light and white surfaces affect how historical spaces are perceived and enhanced. This article analyzes, through photographic documentation and illuminance measurements, aims to analyze how the predominance of white on the interior walls, combined with the villa's particular architectural configuration, influences the luminous quality, chromatic perception, and user experience. Despite their neutrality, the white walls transform into dynamic surfaces, allowing natural light to be reflected and diffused, increasing brightness and promoting an even distribution of light. This creates a sense of openness, lightness, and spatial continuity, making rooms more welcoming for office activities. The combination of white and natural light promotes user well-being, concentration, and a serene environment. The study emphasizes the importance of combining chromatic analysis and lighting technology to preserve and improve historic structures.

Keywords: Natural light; White interiors; Historic buildings; Architectural valorization.

Introduction

The quality of natural light and the color choice of surfaces represent two fundamental factors in the perception and enhancement of architectural spaces, particularly in historic environments intended for new functions. Villa Argentina, home to the USI Academy of Architecture in Mendrisio, is an emblematic example of how the predominance of white on the interior walls can interact with natural light to create welcoming, dynamic environments that are in continuous dialogue with the external context. Architectural literature has long recognized the central role of natural light as a "building material" capable of animating and transforming space. Light not only defines space but also imparts a perceptual, emotional, and, even “spiritual” character to it. "Space is oblivion without light" (Holl, 2006). Le Corbusier stated that "light creates the environment and the feeling of a place, just as it expresses a structure," highlighting the indissoluble link between light, form, and perception (Bathurst, 2020)

Recent studies have also shown that the reflectance of white surfaces increases the distribution and intensity of natural light, promoting a perception of openness and spatial continuity, and enhancing architectural details and materials (Espinoza-Sanhueza *et al.*, 2025). The relationship between light and color has been the subject of numerous experimental studies highlighted how the choice of materials and colors profoundly affects the luminous qualities and the psychophysical perception of environments (Makaremi *et al.*, 2019). In particular, the presence of white surfaces allows for a more intense perception of the variations in tone and temperature of natural light throughout the day, making spaces dynamic and ever-changing (Simm and Coley, 2011). Moreover, natural light carries the chromatic nuances of the external landscape into the buildings, enriching the perceptual experience and strengthening the dialogue between interior and exterior.

Through systematic photographic documentation and lighting measurements conducted during the central hours of the day, this article aims to explore how natural light is reflected and diffused by the white interiors of Villa Argentina, influencing the perception of spaces, the relationship between interior and exterior, and user comfort. The objective is to offer an integrated reading between

chromatic and lighting analysis, suggesting design and conservation strategies that can also be applied to other historical contexts where white and light neutral surfaces are present.

Fig. 1 – Villa Argentina

Historical-architectural context

Villa Argentina, located in Mendrisio in the Canton of Ticino, represents one of the region's most significant testimonies of nineteenth-century residential architecture. Designed by architect Antonio Croci between 1872 and 1873 on commission from Giovanni Bernasconi, an entrepreneur active in Argentina, the villa originally served as a summer residence. It is located at the foot of a hill within a large park rich in rare tree species, such as magnolias, Himalayan cedars, pines, and a two-hundred-year-old elm, which integrates the building into the greenery in a highly valuable natural setting (*Villa Argentina | ticino.ch*, 2025).

From a distributive point of view, the villa is developed over two above-ground floors plus a mezzanine, rising on a base that supports a double sequence of perimeter loggias. These loggias create colonnades surrounding the building on all sides, evoking Palladian geometries and simultaneously South American colonial architecture, a tribute to the client's experiences in Argentina. The floor plan is rectangular and enriched by a large central skylight, set on a circular drum, allowing natural light to penetrate the villa's heart and illuminate an internal helical staircase.

The interiors, now primarily characterized by white surfaces, have been adapted to the needs of the USI Academy of Architecture, which has occupied the villa since 1989 with the Direction, the Secretariat, administrative offices, logistical services, and various research institutes (*USI*, 2025). This functional transformation involved some modifications, such as the conversion of the original French doors into simple windows and the adaptation of spaces for academic use, while preserving the classical and exotic architectural and decorative elements, which together establish a relationship between the interior and exterior, enhancing natural light as a structural and perceptual element. The choice of predominantly white interior surfaces, in addition to meeting contemporary functional needs, enhances the brightness of the spaces and the chromatic dialogue with the external landscape, providing a foundation for a deeper reflection on the role of light and color in the perception of historic spaces.

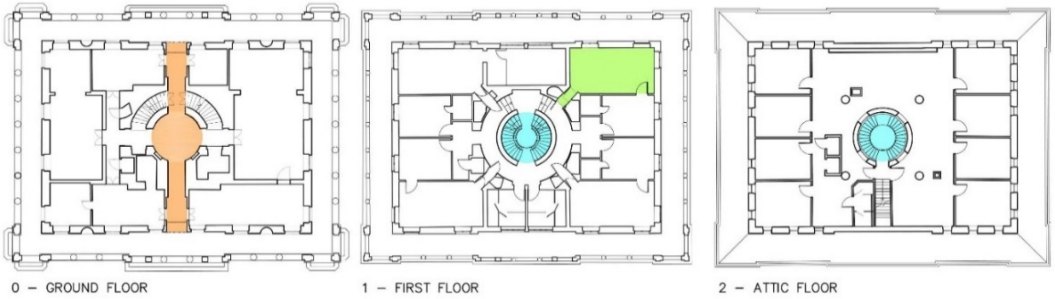


Fig. 2 – Plans of the Villa and areas involved in the photographic survey

Methodology
The methodological approach adopted for the study of the interiors of Villa Argentina is based on the integration of photographic documentation and instrumental measurements of the lighting and chromatic conditions of the environments.

Photographic documentation
The photographic collection focused on three main areas of the villa, in different lighting conditions and from multiple viewpoints. Photography is recognized as a fundamental tool both for the preservation and for the study of the visual perception of architectural environments (Acar, 2018).


Fig. 3 – Photographic documentation of the atrium and corridor


Fig. 4 – Photographic documentation of the Director's office with interstitial space light by canon à lumiere


Fig. 5 – Photographic documentation of the main stairwell

Illuminance and spectrophotometric measurements
Parallel to the photographic documentation, illuminance measurements were taken in the same three representative rooms of the villa, selected based on their function, exposure, and architectural features. A lux meter was used to measure illuminance levels (expressed in lux), an instrument widely employed to evaluate the amount of light present in a space and its distribution. The measurements were conducted during the central hours of the day, when natural light reaches peak intensity and in most uniformly distributed in indoor environments, as recommended by CIE 117:1995 (Commission Internationale de l'Éclairage, 1995). In this specific case, the measurements were taken in these three situations. For the management offices on 17/7/2024 between 12:00 and 13:30. For the central staircase under the skylight on 24/7/2024 between 12:30 and 12:45. For the longitudinal corridor with the attached central atrium on 24/7/2024 between 13:30 and 14:15.

A spectrophotometer was also used to analyze the properties and quality of light in the management office. The combined use of a luxmeter and a spectrophotometer allowed for the correlation of

quantitative data on illumination with qualitative data related to the color rendering of surfaces, offering an integrated view of the perceptual conditions of the spaces.
The achieved illumination levels were compared with the standards required by the EN 12464/1: 2021 regulation "Lighting for work places – Part 1: Indoor work places" (‘UNI EN 12464-1:2021 - UNI Ente Italiano di Normazione’, 2021).

Geographical location, orientation of openings, angle of incidence of light:
In Fig. 6, the plan shows the position of the villa, its orientation, and the position of the windows/doors/loggias about the cardinal points and seasonal solar paths.
During the surveys, light fell on the three surveyed environments at an altitude of:

- 63.56° Directorate's office at 17/7/2024 - 155.71° azimuth
- 63.57° Atrium and Corridor at 24/7/2024 - 179.67° azimuth
- 61.49° Main stairwell at 24/7/2024 - 155.71° azimuth

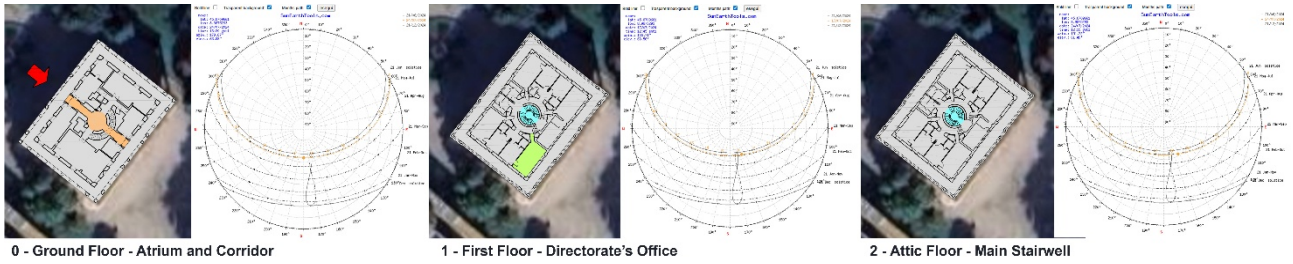


Fig. 6 – Orientation of openings on the ground floor and first floor concerning the North and corresponding solar diagram

Weather conditions:
The weather conditions at the time of the measurements were clear skies during the readings of the central stairwell, the corridor, and the central atrium on the ground floor. During the measurements in the directorate’s office, the weather conditions were variable and partially cloudy.

Correlated Color Temperature of light:
The color temperature was measured using a spectrophotometer in the directorate's office, with an average of 3 readings. The measurement of only natural light resulted in a value of approximately 5700K. The room was illuminated by natural light, but with the lighting fixtures turned on, the CCT was approximately 4800K. With only artificial light, the CCT was measured at 3300K once the blinds were lowered.

Characterization of white and relations with other material chromacity:
In a study on the restoration of the Villa (Graf and Nozza, 2024), where some solutions were developed to recover the original state of the paintings. Some alternatives were proposed regarding the historical solutions adopted initially in the environments, white paints were considered according to the NCS standard (Hård and Sivik, 1981). This standard is a color classification system based on human visual perception. The various shades are identified through codes that indicate color nuances and degrees of brightness. The final color is based on six primary colors (white, black, red, yellow, green, and blue), which, when mixed in different quantities, also allow for the distinction of various shades of white used in the paint industry.
The white detected in the villa's interiors is NCS S 0500N, a neutral white that is very close to pure white and without perceivable color dominants (the letter "N" stands for Neutral). It is a technical white, very similar to titanium white (titanium oxide - TiO_2), which is usually used to achieve pure and bright whites in paints. It does not have the warm tones of lime white nor the dusty ones of chalk:

it is cold, clean, and artificial, typical of modern or industrial contexts where a neutral and bright effect is sought. The NCS S 0500N white harmoniously matches the materials present in the building, such as the marble and stone of the main stairwell, the light marble of the corridors and atriums, and the warm parquet of the Directorate's office. Its neutrality enhances the natural veining of the stone surfaces and creates an elegant contrast with the wood, providing brightness and visual coherence to the environments. In Fig. 7, it is possible to observe a comparison between the detected color and other shades of white, along with the chromaticity of the other materials of the villa's interior.

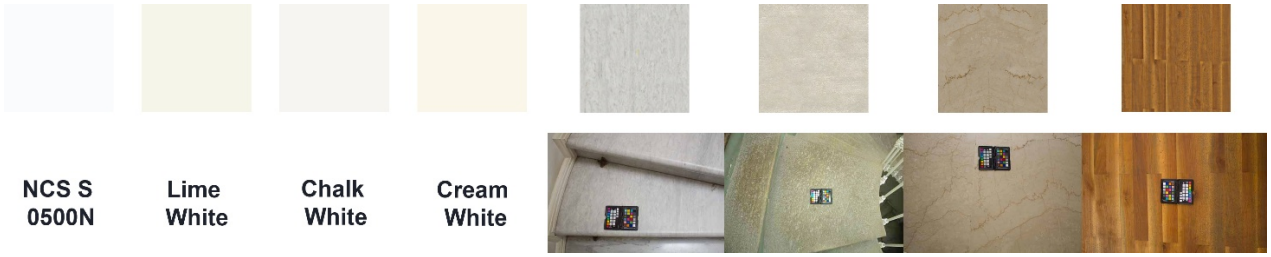


Fig. 7 – White NCS S 0500N and comparison with other whites

Results and Analysis

The collected data were analyzed with the aim of evaluating the distribution and intensity of natural light in the different areas. In particular, in the directorate's office, the influence of the presence or the absence of the bicolored striped curtain, which is part of the proposed guidelines for the recovery of the building, has been evaluated.

Distribution and quality of natural light in the Director's office

The measurements of illuminance and light quality were carried out using a spectrophotometer positioned at the center of the desk group in the management area.

Under conditions of only artificial light, the recorded values were: Em = 525 lux, CCT = 2889 K, and Ra = 84.

With the combination of natural and artificial light, the illumination increased to Em = 743 lux, with a correlated color temperature (CCT) of 3283 K and a color rendering index (CRI) of 89.

In the exclusive presence of natural light, the recorded values were Em = 198 lux, CCT = 4747 K, and Ra = 97.

Finally, with the use of external solar shading (lowered roller blinds) and natural light, the measured parameters were Em = 187 lux, CCT = 4855 K, and Ra = 98.

As reasonably expected, the quality of daylight, expressed through the color rendering index (Ra) (Bess, 1987), is significantly superior to that generated by the artificial lighting fixtures in the analyzed environment.

Distribution of natural light in the Director's office

The measurements taken with the luxmeter were conducted on the entire set of tables in the director's office using a grid of points, arranged according to the aforementioned EN 12464/1 standard. The results, shown in Figure 8, indicate that even under variable sky conditions, the average illumination required for working in Visual Comfort is not achieved if the external blinds, as stipulated by the restoration guidelines for restoring the original configuration of the loggias, are positioned lower. As specified by the regulations, visual comfort is intended as the work performance of users with normal or corrected ophthalmic visual capacity.

Distribution of natural light in the interstitial space "Canon à lumière"

The designer Antonio Croci has devised an ingenious system of 4 cylindrical chimneys that bring air and light to the rooms on the first floor, hallways, interstitial spaces between the offices, and the

circular corridor. It was therefore interesting to verify how much light these "canon à lumiere" actually brought.
Measurements taken in the center of the plexiglass surface, placed as a covering of the Canon à lumiere, gave 12 lux with a spectrophotometer, and a ground measurement of 3 lux in the center of the interstitial space with a lux meter. This results in a not very significant contribution of the light brought by the light duct inside the area, the neighboring management office, and the corridor.

Distribution of natural light in the main stairwell
For the stairwell, a grid of points was used, positioned on the surface of the individual steps, as shown in Figure 9. As specified by the regulations, the grid was designed to be rectangular and external to the circular shape of the staircase's outer profile. The average illuminance Em was found to be 11422 lux, well above the standard of 100 lux for passage areas, thanks to the presence of the large skylight at the top of the stairwell. The uniformity, on the other hand, was 0.31, lower than the 0.4 required by standards for spaces dedicated to this function. Probably the result was non-compliant because part of the staircase near the second floor was directly illuminated by sunlight.

Distribution of natural light in the central atrium and corridors
To measure the illuminance in the central atrium, which benefits from the light coming from the circular skylight on the roof, and in the two corridors that connect the central atrium to the north and south entrances of the villa, which benefit from the light coming from two respective French doors, a single grid of points was used. The results are, for simplicity, shown in three distinct zones. South Corridor, North Corridor, and Central Atrium, as shown in Figure 10, on a clear sky day, it was found that:
Central atrium - the average illumination Em was found to be 486 lux and the standard was met. The calculated uniformity was 0.37, slightly lower than the standard.
South Corridor - the average illuminance Em was found to be 701 lux, significantly exceeding the standard required by the regulations. The measured uniformity is 0.36, slightly below the standard.
North Corridor - the average illuminance Em was found to be 388 lux, also exceeding the standard here, despite the north exposure. In this case, the standard requirement regarding Uniformity was also met.
The use of NCS S0500N white paint, along with the presence of the large central skylight and the connection with the central atrium and the two longitudinal corridors, has allowed for the satisfaction of Visual comfort standards with only natural light on a day with a clear sky during the central hours of the day.

Conclusions
This study on Villa Argentina in Mendrisio, home to the USI administrative offices, demonstrates how using a bright neutral white—specifically NCS S 0500N—combined with thoughtful architectural design, promotes the effective entry and uniform diffusion of natural light throughout the building. Thus, the users' visual comfort is improved, enhancing the workers' quality of life and well-being. Even if uniformity has not always been fully achieved, the use of large skylights and French windows has increased the amount of light reflected on white surfaces. The loggias and the curtains that were originally installed limit the direct sunlight, thereby reducing glare for users while still providing high-quality indirect lighting for them. These results, which are supported by photographic documentation and lighting surveys, are useful for providing methodological insights for the restoration and conservation of other historic buildings, where natural light, in combination with architecture and colors, can create welcoming and functional spaces.

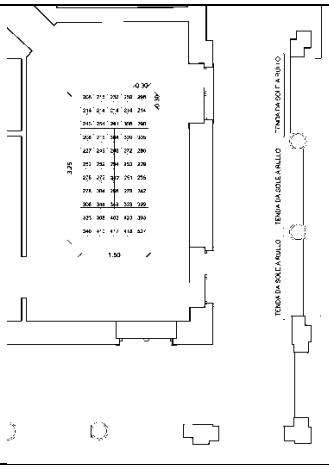
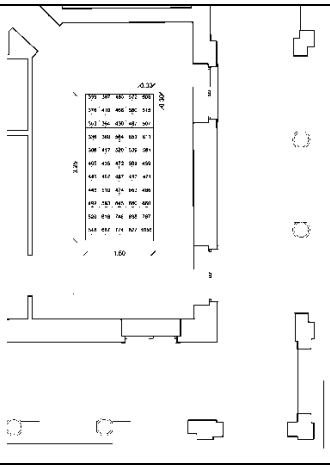
Directorate's office - Detection height = table surface	
roller blinds in the lowered position AVERAGE ILLUMINANCE Em = 293 lx (Standard = 500 lx) Emin = 208 Emax = 527 UNIFORMITY Uo = 0.71 (Standard = 0.6)	roller blinds in the raised position AVERAGE ILLUMINANCE Em = 536 lx (Standard = 500 lx) Emin = 336 Emax = 1056 UNIFORMITY Uo = 0.63 (Standard = 0.6)
	

Fig. 8 – Distribution and natural light in the Director's office

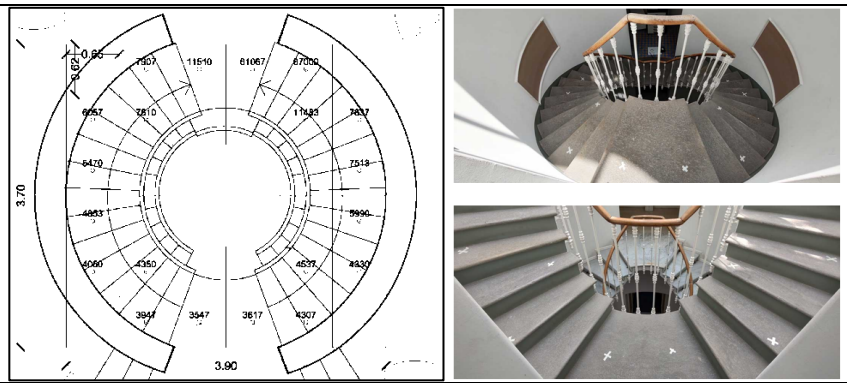
The main stairwell
AVERAGE ILLUMINANCE Em = 11422 lx (Standard = 100) Emin = 3547 Emax = 67000 UNIFORMITY Uo = 0.31 (Standard = 0.4)


Fig. 9 – Distribution and natural light in the main stairwell

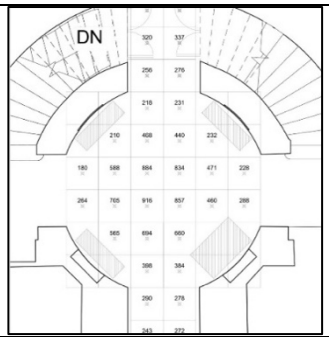
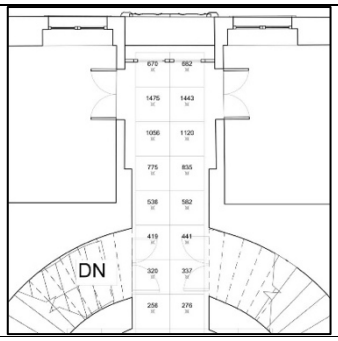
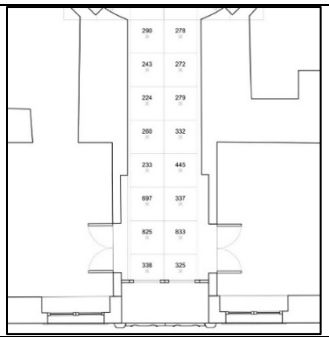
Central atrium	South Corridor	North Corridor
AVERAGE ILLUMINANCE Em = 486 (Standard = 100) Emin = 180 Emax = 916 UNIFORMITY Uo = 0.37 (Standard = 0.4)	AVERAGE ILLUMINANCE Em = 701 (Standard = 100) Emin = 256 Emax = 1475 UNIFORMITY Uo = 0.36 (Standard = 0.4)	AVERAGE ILLUMINANCE Em = 388 (Standard = 100) Emin = 224 Emax = 883 UNIFORMITY Uo = 0.58 (Standard = 0.4)
		

Fig. 10 – Distribution and natural light in the central atrium and corridor

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Hue cancelation experiments and the quantum perceptual color space

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Abstract

A novel paradigm for understanding color perception, grounded in quantum information theory, has been recently proposed. Departing from classical CIE colorimetry models, the quantum model focuses on the intrinsic mathematical properties of color sensations, revealing an inherently hyperbolic chromatic space which aligns with experimental observations over the past century. By interpreting this hyperbolic space as the state space of a quantum system, the model uses the rigorous framework of quantum information theory to explain established phenomena like chromatic opponency and predict new properties useful in image processing. Perceptual colors are treated as quantum observables, with their states represented by density matrices. This approach draws a direct connection to Hering's chromatic opponency theory, where color perception is modeled as superpositions of incompatible chromatic states (red-green, yellow-blue). Quantum measurements in this framework are inherently probabilistic, with perceived colors constrained within a finite convex subset known as the color solid, reflecting the real limits of human color perception. The model introduces novel mathematical tools to describe state transformations induced by perceptual measurements, linking them to well-established theories in physics. Furthermore, the quantum model rigorously defines chromatic attributes such as hue and saturation. This precise mathematical formulation eliminates the circularity often found in traditional color theory definitions and offers a coherent framework for understanding complex color phenomena. Applications of this model extend to practical domains such as white balance correction in imaging, where it outperforms classical methods in reducing color casts. These promising results highlight the potential of the quantum approach in technological applications. However, to fully validate and refine this innovative model, comprehensive visual experiments are essential. The theory predicts new perceptual phenomena and offers fresh interpretations of known effects, but empirical verification is crucial. We call upon the scientific community to engage in collaborative efforts to design and execute experiments that can rigorously build the chromatic state space of the quantum model by means of the well-known hue cancelation techniques

Keywords: Color perception; Quantum information, Chromatic opposition, Visual experiments.

Introduction

During the late 19th century, prominent scientists such as Riemann, Maxwell, Grassmann, and von Helmholtz began to recognize that the set of perceptual colors, which we denote by C, should not be understood merely as a collection of subjective sensations, but as a space with a well-defined and nontrivial mathematical structure.

It was Schrödinger, in his foundational work (Schrödinger,1920), who first formalized this intuition by establishing a set of axioms showing that C forms a 3-dimensional regular convex cone. This geometric insight laid the groundwork for subsequent axiomatic approaches to color perception.

Decades later, Resnikoff refined Schrödinger's analysis in (Resnikoff,1974), proving that C is not only a convex cone but also a homogeneous space. This result implies that C must be isomorphic to one of two canonical spaces: either $[0,+\infty)^3$ or $[0,+\infty)$ x H, where H is a two-dimensional hyperbolic space.

C represents an idealized perceptual space, meaning it includes all virtually possible color sensations in isolation, independently of the physiological thresholds imposed by human vision at very low or very large light intensities.

The Cartesian space $[0,+\infty)^3$ is the underlying geometric structure of standard colorimetric models such as those promoted by the CIE (Commission Internationale de l'Éclairage). However, these models are not well suited to capture the intrinsically perceptual aspects of color experience. In contrast, the space $[0,+\infty)$ x H exhibits significantly richer algebraic, geometric, and perceptual properties. Therefore, in the rest of this work, we focus exclusively on this second option.

Notably, the space $[0,+\infty)$ x H is isomorphic to the cone of 2x2 real symmetric positive-semidefinite matrices, which in turn is isomorphic to the closure of the future lightcone in the 3-dimensional Minkowski space.

In his concluding remarks, Resnikoff observed that these spaces also coincide with the domains of positivity of the only two 3-dimensional, non-associative, formally real Jordan algebras (see, e.g., (Baez,2012) for more information about Jordan algebras): H(2,R), the Jordan algebra of real symmetric 2x2 matrices and the so-called spin factor $\mathbb{R} \oplus \mathbb{R}^2$, equipped with suitable Jordan products. These two Jordan algebras are naturally isomorphic, providing the possibility to deal with a matrix-based framework or a vector-based one.

The quantum information-theoretic model we introduce in the next section is based on the assumption that these naturally emerging Jordan algebras encode the structure of the quantum observables relevant to color perception. This identification provides both a geometrically grounded and algebraically coherent foundation for our approach.

The Bertier-Provenzi quantum-information model of color perception

The trace of an element (a,v) of $\mathbb{R} \oplus \mathbb{R}^2$ is equal to 2a, so the unit trace elements of the spin factor are in one-to-one correspondence with the density matrices of the rebit, i.e. the unit trace matrices belonging to the domain of positivity of the algebra H(2,R). The state space of the rebit is labeled by the points of the unit disk D in the real plane, called Bloch disk.

Vectors of the Bloch disk represent *chromatic states*, and Hering's color opponency involving the two pairs of unique hues is encoded by means of the two Pauli matrices with real entries, i.e.

$$\sigma_1 = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}, \quad \sigma_2 = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}.$$

In the sequel, we will denote with σ_0 the identity 2x2 matrix.

As in the case of qubits, we can decompose any density matrix of the rebit using the basis $(\sigma_0, \sigma_1, \sigma_2)$:

$$\rho(s_1, s_2) = \rho_0 + \frac{s_1}{2}\sigma_1 + \frac{s_2}{2}\sigma_2.$$

$\rho_0 = \frac{\sigma_0}{2}$ and s_1, s_2 are the expectation values of the real Pauli matrices in the state ρ.

Using polar coordinates, we can write

$$\rho(s_1, s_2) = \rho_0 + \frac{s_1}{2}[\rho(1,0) - \rho(1,\pi)] + \frac{s_2}{2}[\rho(1,\pi/2) - \rho(1,3\pi/2)].$$

For all angle θ, $\rho(1,\theta)$ is a rank-1 projector, i.e. a pure state, and $\rho(1,\theta_1)$, $\rho(1,\theta_2)$ project on orthogonal directions precisely when the two angles correspond to antipodal points on the unit circle. Since orthogonality in quantum theories represents incompatible states, *the previous equation codifies a generic chromatic state as the superposition of two chromatic opponencies between incompatible states, red-green and yellow-blue in Hering's theory, weighted by the expectation values of the real density matrices, plus an offset state represented by* ρ_0.

The density matrix ρ_0, associated with the center of the Bloch disk, is the *maximally mixed state*, characterized by the fact of having maximal von Neumann entropy and not carrying any chromatic information. Therefore, the density matrix ρ_0 represents the *achromatic state*, and the previous equation is exactly the quantum description of the chromatic information that can be gathered from an isolated color stimulus in Hering's theory.

Figure 1 summarizes what just discussed.

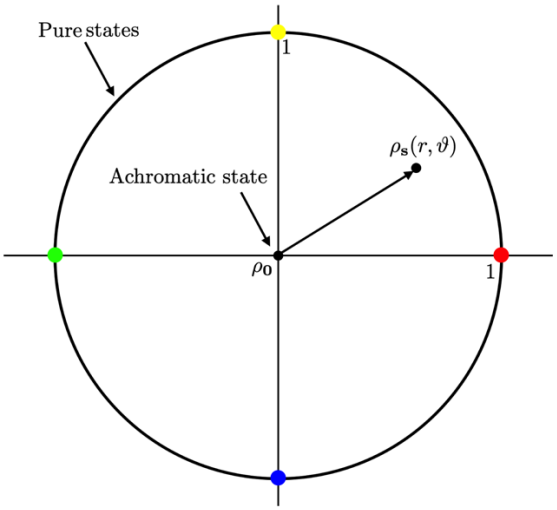

Figure 1: the graphical representation of the Bloch disk with the opponency axes, the achromatic state and a generic chromatic state in polar coordinates.

The new paradigm at the heart of the model of color perception is based on the interpretation of perceived colors as the results of quantum measurements performed by observers from chromatic states.

The uncertainty relations for chromatic opposition

In the paper (Berthier & Provenzi, 2021), the existence of uncertainty relations for chromatic opposition have been proven theoretically. The final result of that study is contained in the following inequality:

$$(\Delta s_1)^2 \cdot (\Delta s_2)^2 \geq \frac{r^4}{4} \sin^2(2\theta),$$

where on the left-hand side there appear the variances of the expectation values of the Pauli matrices.

The interpretation is the following.

- If $\theta = 0, \frac{\pi}{2}, \pi, \frac{3\pi}{2}$, then the right-hand side is 0 and to the inequality is trivial. Those angles represent the axes of chromatic opponency red-green and yellow-blue, hence if a color stimulus is perceived to be on one of those axes, then there are no uncertainty rules.

- If θ is different than the previous values, then the color is perceived outside the opponent axes and there will be uncertainty: the measurement of the red-green opponency encoded by s_1 by any experimental protocol will produce a disturbance on the measurement of the yellow-blue opponency encoded by s_2, and vice-versa.

The level lines of the quantity on the right-hand side of the previous inequality are plotted in Figure 2. It can be seen that there is an increment of one order of magnitude passing from chromatic coordinates near the opponency axes, to those at an angle $\pi/4$ with respect to those axes.

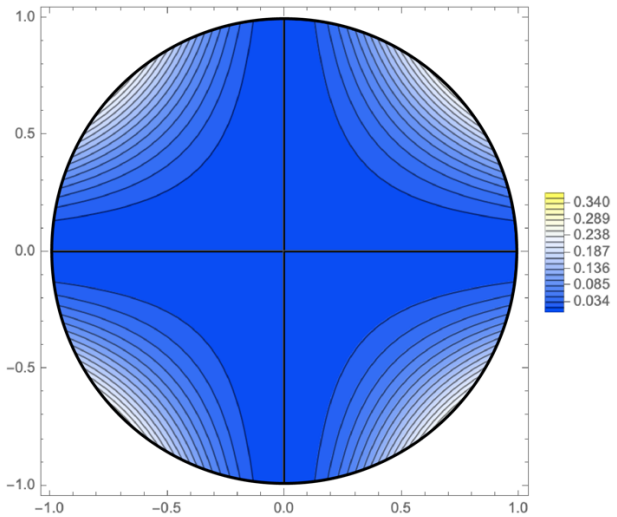

Figure 2: plot of the level lines of the quantity on the right-hand side of the uncertainty relations.

An experiment to test the actual existence of these uncertainty rules can be performed, for instance, using the hue cancelation method of Jameson and Hurvich (Jameson & Hurvich,1955): after the identification of the four unique hues (red, gree, yellow and blue) for the observer, the hue cancelation should be performed several times. It is well-known that the results of these experiments are not sharp, but follow a stochastic behavior, thus allowing the calculation of the mean and variance required to test the theoretical prediction.

If the product of the variances follow the analytical path established by the uncertainty inequality, a first direct proof of the validity of the Berthier-Provenzi model could be achieved.

Conclusions

The Berthier-Provenzi quantum-information model of color perception predicts the existence of Heinsenberg-like uncertainty relations for chromatic opposition. The experimental verification of this prediction would be a major discovery because it would prove the existence of quantum features in the processing of color information performed by the human visual system.

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Interactions of daylight and electric light with indoor colored surfaces: Effects on human circadian response

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Abstract

With the rise in time spent indoors by people and the growing awareness of the circadian effects of light, the design of integrative lighting solutions that support health and well-being becomes crucial. In this context, the characteristics of surfaces in the built environment are fundamental. By reflecting, absorbing, and transmitting light, surfaces contribute to defining the spatial and spectral distribution of light in spaces and the spectral irradiance at people's eyes, in turn determining their circadian response. This could be particularly true for surfaces with selective reflectance. At this time, researchers have investigated this topic mostly considering how colored walls and furniture alter electric light or daylight spectral power distribution separately. Yet, no study has considered both of them in the same space. To fill this gap, in this paper, spectral irradiance measurements are carried out in a room where different layouts are obtained by alternatively assigning white, blue, and red colors to one indoor wall, setting three electric light CCTs (3000 K, 4000 K, and 6000 K), and repeating the measurements for different daylight conditions. For each measured spectrum, melanopic daylight efficacy ratio (melDER) values are obtained. Hence, percentage differences (PDs) are calculated by comparing the melDER at the eye level against that of the source for both electric light and daylight. The higher the PD, the greater the alteration of the spectrum of the primary light source caused by the wall's colour. Results show that melDER values at the eye level always differ from those of the primary light source. Consequently, contrary to the expectation, also white determines variations in melDER. For electric light, white and red colors determine a reduction of melDER with PD values up to -13% and -26% respectively; conversely, a slight increase of melDER (PD equal to 3%) occurs with blue. Small differences in PDs are observed for different CCTs. Similar trends are observed for daylight. Again, white and red colors determine an average reduction of melDER, while a slight increase occurs with blue. However, due to the highly dynamic nature of daylight, more nuanced interactions with colored surfaces occur, with PD values strongly influenced by sky conditions, season, time of day, and the resulting depth and incident angle of daylight penetration.

Keywords: integrative light, melanopic daylight efficacy ratio, indoor wall color, spectral reflectance, daylight and electric light spectral measurements.

Introduction

Across the globe, people spend a considerable portion of their lives within built environments as a consequence of urbanization, technological advancements, and the current nature of both work and leisure activities. This modern lifestyle, characterized by a significant shift towards indoor living compared to the past, has reshaped the relationship between humans and the natural environment, radically changing the conditions to which humans have been accustomed to for millennia. This issue requires reconsideration of building design to face the new prevalent indoor existence and preserve human health and well-being. In this context, the role of daylight inside buildings (and when it is absent or scarce, of electric light) must not be ignored. Indeed, it is well-established that light affects human life in multiple ways besides vision (Vetter *et al.*, 2021), encompassing mood, productivity,

and sleep-wake cycle (Konstantzos *et al.*, 2020; Xiao *et al.*, 2021). Specifically, awareness of the circadian effects of light has spread following the identification of intrinsically photosensitive retinal ganglion cells (ipRGCs), which were found to drive the human circadian rhythm, and the definition of their spectral sensitivity to light. This understanding has led to a shift from traditional lighting solutions to *integrative lighting* ones (Commission Internationale de l'Eclairage, 2024), boosting the design of spaces that support both visual and circadian needs.

In this respect, the choice of surfaces' color is crucial. In particular, colored surfaces selectively reflect and absorb light, contributing to the definition not only of luminance patterns and illuminance levels, but also of the shape of the spectrum reaching people's eyes, which stimulates the ipRGCs and determines people's circadian response. For instance, in (Bellia *et al.*, 2017) it was found that, in a space lit by electric light, the violet color caused a considerable variation of circadian stimulation compared to the case with all neutral white walls, but pink and white colors provided comparable results. Similarly, it was observed that even in daylit spaces, surfaces colored in yellow, blue, and light grey provided lower circadian stimulation if compared to the case with all neutral white walls (Hartman *et al.*, 2014, 2017), and that blue-tinted walls provided higher circadian stimulation than orange ones (Potočnik and Košir, 2020). Also, in (Bellia *et al.*, 2024) it was shown that the interaction between electric light and walls' spectral reflectance is crucial, since even low reflective surfaces with appropriate spectral composition can support good circadian entrainment if combined with electric light with high correlated color temperature (CCT).

However, at this time, researchers have investigated the impact of colored walls and furniture on the spectral power distribution of electric light or daylight separately, and a comprehensive understanding of their combined effect remains underexplored. However, daylight and electric light are characterized by totally diverse spectral power distributions; therefore, it is possible that the two sources could interact in different ways with the spectral properties of walls. This topic deserves attention as both light sources coexist and interact in real-world environments. Furthermore, it must be noticed that previous studies have often compared the effects of colored surfaces on circadian stimulation by evaluating the circadian stimulus (CS), melanopic equivalent daylight illuminance (melEDI), or equivalent melanopic lux (EML) obtained in spaces where colors with different total reflectance values were used. This introduces a potential confounding variable: Variations in circadian stimulation could have been influenced by either the spectral composition of the radiation reaching the eyes and its quantity, which is directly related to the walls' total reflectance. Assuming that, in general, the use of surfaces with higher total reflectance values always determines higher illuminances at the eye and consequently higher non-visual responses, it is essential to understand, given equal total reflectance, which role the spectral one plays in altering the shape of the spectrum at the eye and determining melEDI values.

Based on these considerations, this study examines whether walls color differently affects the shape of the spectrum reaching people's eyes in both daylit and electric lit spaces. The analysis is based on a comparison between the melanopic daylight efficacy ratio (melDER) values measured indoors at eye level and those corresponding to the primary light source (for both electric light and daylight), as melDER depends only on the shape of the spectrum, not on the total irradiance. Irrespective of the total reflectance, the more selective the indoor surfaces, the higher the differences between the melDER of the source and that at the eye level.

For the scope of the study, on-field spectral measurements were carried out in a room where different configurations were obtained by combining three wall colors, three electric light CCTs, and repeating the measurements for different daylight conditions.

Method

A rectangular office in Naples (40°84'66'' N, 14°24'79'' E), measuring 3.50 m in width, 2.80 m in depth, and 2.70 m in height, was used as a case study (Fig. 1 and Fig. 2). The only furniture in the room was a grey desk (ρ_{D65} = 57%), where a person was supposed to be sitting, looking straight ahead. Different room configurations were obtained by alternatively assigning white (ρ_{D65} = 83%), blue (ρ_{D65} = 13%), and red (ρ_{D65} = 17%) colors to the indoor wall in front of the observer. These colors were chosen because of their spectral properties. In particular, white presents almost constant reflectance values at each wavelength, while blue and red are mostly reflective in the short and long wavelength intervals, respectively. For this reason, it is expected that the configuration with the white wall will cause the lower variation of the primary light source's melDER, while blue and red walls will cause an increase and decrease of the primary light source's melDER, respectively. All the other walls in the room were kept white (ρ_{D65} = 76%). Two tunable LED sources were installed in the room, and their CCT was set equal to 3000 K, 4000 K, and 6000 K alternatively (Fig. 3). Their normalized spectral radiance is reported in Fig. 3b. They have been measured by means of a Konica Minolta SC 2000 spectroradiometer (Konica Minolta CS 2000 technical sheet) located perpendicular under the source directed towards the barycenter of the luminaires. A South-oriented French window (1.55 m wide and 2.60 m high) with a wooden frame (ρ_{D65} = 15%) and a neutral double pane glass (τ_{D65} = 76%) allowed daylight entrance.

For each room configuration, the spectral irradiance at the eye level (for both electric light and daylight alternatively) was measured by means of a GL Spectis 1.0 spectroradiometer (GL SPECTIS 1.0 Touch & Flicker technical sheet) mounted on a tripod to simulate the typical position of the eye of a person sitting at the desk, 1.20 m above the floor, 1.75 m and 1.88 m distant from the facing wall and the window, respectively. Specifically, for electric light, measurements were performed with the luminaires set to provide 500 lx on the worktop of the desk (the typical work plane illuminance prescribed for office tasks by the Standard (CEN, 2021)). During these measurements, daylight was excluded by using an external roll-up shutter and an indoor white curtain (ρ_{D65} = 83%). Differently, both systems were open to carry out daylight measurements (Fig. 4). In more detail, daylight spectral irradiance was measured over 12 days during summer (between June and July 2023) and 12 days during winter (between January and February 2024), from 10:30 to 17:30 with a 1-hour time step. Measurements were repeated for 4 days for each color of the indoor wall. Outdoor vertical daylight spectral irradiance was measured on the window plane contextually with the indoor spectral irradiance at the eye level, as shown in Fig. 1. During the measurement period, different weather conditions occurred. They have been classified in clear (no clouds), intermediate (some clouds), and overcast (sky completely covered by clouds) according to the cloud cover evaluated through photos of the sky vault taken simultaneously to measurements.

For each measured spectrum, melDER values were obtained through the CIE S026 α-opic Toolbox (CIE S 0 26 a-opic Toolbox, 2020). Hence, percentage differences (PD) were calculated according to the following equation:

$$PD = (melDER_{eye} - melDER_{source}) / melDER_{source}$$

where $melDER_{eye}$ was the melDER at the eye level, while $melDER_{source}$ was the corresponding value referred to electric light and outdoor daylight. The higher the PD, the greater the alteration of the spectrum caused by the wall's colour.

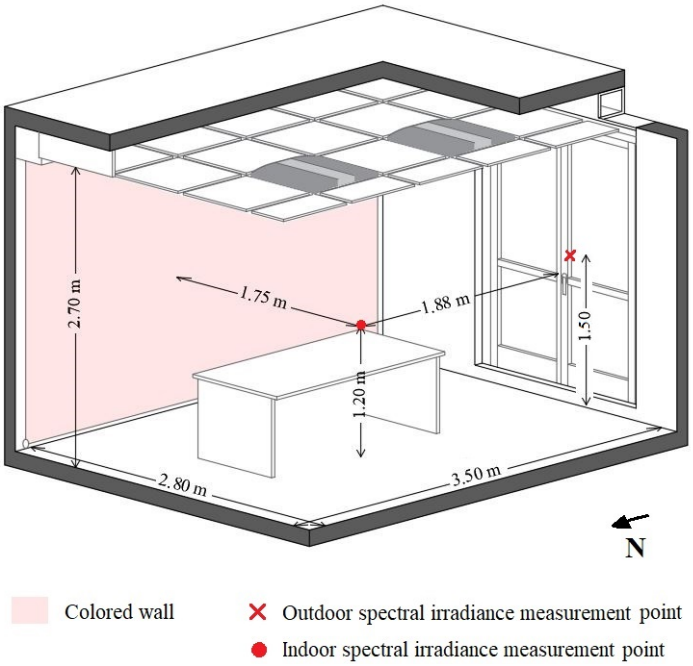

Fig. 1 - Axonometry of the case study with the main dimensions and the indication of the points of measurements

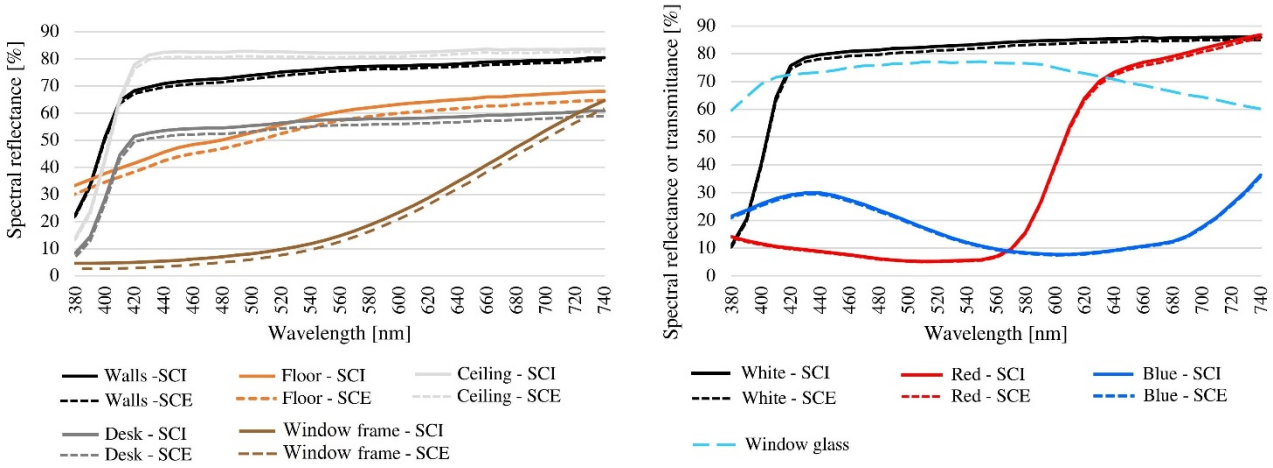

Fig. 2 - Spectral reflectance - with the specular component included (SCI) and excluded (SCE) - of the surfaces in the room and spectral transmittance of the glass

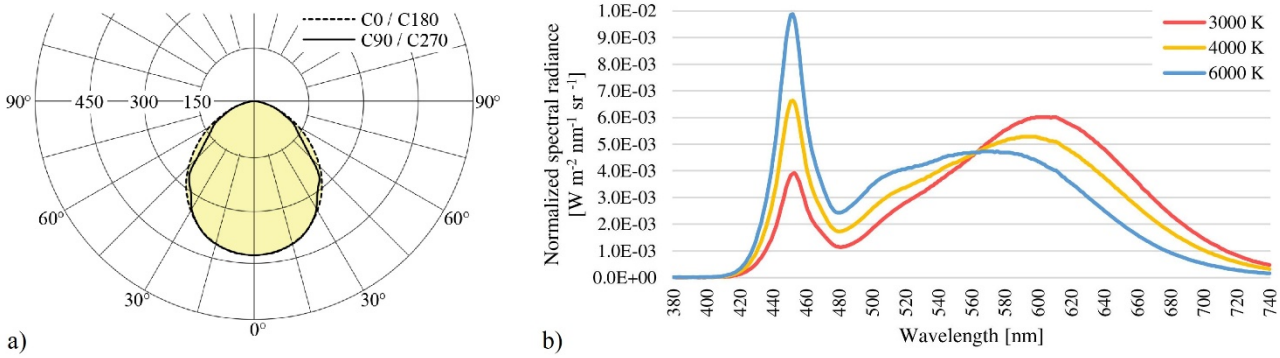

Fig. 3 – Luminaires' photometry (a) and normalized spectral radiance (b)

Fig. 4 – Photos of the room during electric light (a) and daylight (b) measurements for the configuration with the white wall

Results

Fig. 5 represents the PD values referred to electric light (a), daylight in summer (b), and daylight in winter (c). In the scatterplots, when the sky is overcast, the data are marked by means of an asterisk, when it is intermediate, with two asterisks; otherwise, the sky is clear.

Results show that melDER values measured indoors at eye level always differed from those of the primary light source. For electric light, white and red colors caused a reduction of melDER with PD values ranging from -11% to -13% (slightly increasing in absolute value as the CCT increases) and from -21% to -26% (decreasing in absolute value as the CCT increases), respectively; in contrast, a slight increase of melDER occurred with blue, with PD values close to 3% across all CCTs.

Similar trends were observed for daylight, especially during summer. These days, white and red colors led to a reduction of melDER, showing average PD values equal to -7.4% (standard deviation equal to 1.4%) and -17.4% (standard deviation equal to 1.5%), respectively. On the contrary, the blue color generally caused a slight increase of melDER (with values up to 4.9%), but slight reductions (up to -4.4%) were sometimes observed. Overall, the environment seemed to absorb radiation in short wavelengths more in the central part of the day, at 13:30 and 14:30. Indeed, when red was used, the biggest melDER reductions were observed during this time range. As regards blue, the typical observed increase of melDER was lowered (values close to 0) in the time range 13:30-14:30. However, the data registered at 17:30 were an exception to this trend. On the contrary, when the indoor wall was white, melDER reductions oscillated without a trend between -5% and -10%, with only exception for some data at 10:30 and 12:30. This different behavior could be due to variations in daylight directionality, ratio of direct to indirect component inside, and reflection mechanisms between light and surfaces.

During winter, again, white and red colors led to a reduction of melDER. In more detail, results obtained in winter were comparable to those observed in summer, all day long for white, and only in the morning for red, which showed very significant melDER reductions in the afternoon. Unexpectedly, even if the blue color led to a general melDER increase, great reductions occurred in some cases. The variable weather conditions occurring during winter could be a possible justification.

Similarly, this could also be due to different spectral reflectance values in the presence of high incident angles. Nevertheless, it was not possible to find a relation between the results and sky conditions.

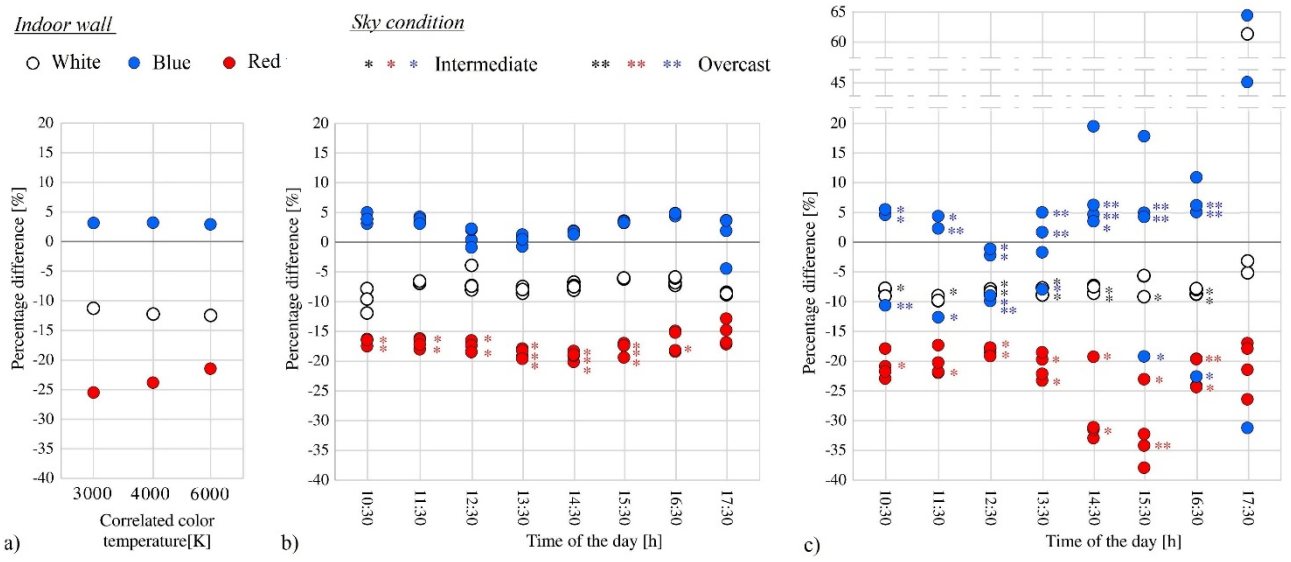

Fig. 5 – Percentage differences obtained for electric light (a) and daylight in summer (b) and winter (c)

Discussion and conclusion

This study has investigated how strongly chromatic indoor walls spectrally modify light coming from the primary light source, contributing to shaping the radiation reaching people's eyes and, in turn, influencing the light-induced circadian response. To this end, spectral irradiance measurements were carried out in an office room in Naples where different layouts were obtained by alternatively assigning white, blue and red colors to one indoor wall, setting three electric light CCTs (3000 K, 4000 K, and 6000 K) and repeating the measurements for different daylight conditions (in summer, with mostly clear skies, and in winter, with different sky conditions).

This study extended previous research by considering the effects of colored surfaces on both electric light and daylight. In addition, compared to existing literature (Hraška and Hartman, 2014; Hartman *et al.*, 2017; Potočnik and Košir, 2020) where daylight measurements were referred to only one day or even one hour, this study presented the results obtained from a prolonged measurement campaign (12 days in summer and 12 days in winter), providing extended information. Moreover, by comparing the melDER at the eye level against those of the primary source instead of CS, or EML, or melEDI, this study quantified the effect of the spectral selectivity of the surfaces on circadian response irrespective of the total reflectance.

In agreement with previous research (Hartman *et al.*, 2014, 2017; Bellia *et al.*, 2017; Potočnik and Košir, 2020; Bellia *et al.*, 2024) this study remarked that colors indoors are fundamental factors influencing light-induced circadian responses, and their choice cannot be based on merely aesthetic considerations. For this reason, designers should move towards a more holistic approach that considers the interplay between light sources and the optical properties of the surfaces in the built environment. Indeed, results showed that melDER values measured indoors at eye level always differed from those of the primary light source, even when surfaces appeared neutral (white wall in this study). Specifically, the blue wall tended to cause a slight increase in melDER, while red and white walls led to a decrease, with these trends generally being true for both electric and daylight sources. However, opposite to electric light, which is static, daylight is highly dynamic; therefore, more nuanced interactions with colored surfaces occurred, with PD values influenced by sky conditions, season, time of day, and the resulting penetration depth and incident angle of daylight.

Despite these contributions, the study has limitations that can be addressed in future research. For instance, to generalize the results, further measures could be conducted in rooms with different geometries and for different gaze directions, to represent the full range of real-world scenarios. Moreover, the palette of colors investigated was limited to white, blue, and red, and future work could explore a broader range of hues, particularly considering colors with similar total reflectance but distinct spectral compositions. Furthermore, the daylight measurements were specific to a particular geographic location (Naples), and results might vary in zones with different luminous climates or depending on different urban contexts. Moreover, despite the merit of this study is to analyze both daylight and electric light in the same environment, the interaction between the two sources has not been analyzed yet. This issue could be addressed in future studies.

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Teaching the building up of the right image in the lighting design visual protocol

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Abstract

In some occasions we have previously elaborated the idea that the lighting design process consists in the laying down of luminances over shapes, surfaces, colours, and volumes, quite in a similar way painters lay down "shadow" and "light" on their canvas. It may also be described as the building up of a meaningful architectural visual situation that, through lighting, assumes its perceptual function in accordance with Richard Williams when he dedicates the question of the visual communication of the architectural intent" to the user he defines as "a non specialized population".

Talking about the "architectural intent" we have already scoured this notion through William MC Lam analysis when he defines lighting's fundamental role in the architecture's perceptual construction, for it assigns a supplement of meaning to the environment, and informs the anticipation of our moving within the architecture, for emotional, and functional purpose.

Rudolf Arnheim, on his side, describes the processes that makes up a pertinent image, in terms of attention catching, by the taking in consideration of the visual dynamic, of the movement and the shape, in the perceptual exercise of "the experiencing of the visual forces", in our case those of the architecture, of the light as an energy and a shape provider, and of the impact of the message along the path of our scouring of the environment. The combination of these notions leads to what we have chosen to define as the "right image", the one delivered by the lighting project in the final phase of the architectural one in the very moment of its acceptation by the customer. The acceptation protocol according to technical and functional expectations inventoried in a specification booklet, is inseparable of an emotional judgement. This final aesthetical statement, as subtle it might be, is in facts tacitly recognized as the definitive demonstration and guarantee of the whole coherence of the project. It is symbolic of the congruency of the visual protocol.

On the contrary, any aesthetically incongruous result, will leave the customer's "beholder's mind" in a state of uncertainty, of an unachieved expectation path, and devaluate the single idea of the lighting design project in some feeling of a betrayal. This perceptual synthesis collimates with the idea of the "symbolic form" as it meets the etymological definition of the "symbol", in the opposition between the "Syn-Ballon" (συμβάλλω) as a contract, a visually sealed one, as a countermark offered to the customer's expectations in order to bring them together, and the "Dia-ballon" (διαβάλλω): its breakdown. It also corroborates Plato and Aristotle's illustrations on this topic, as much as the visual expectations quoted by W. M.C. Lam

The displaying of the various lighting and colour scenes as symbols opens on a pedagogical description of the creative construction of the lighting design and of the colour project. In the meantime it might find a convergence with the already exposed topic of the "Semiotic of light".

Keywords: Lighting design, Semiotic of light, Architecture, Image, Visual Culture.

Introduction

Scouring some of the most important statements and reflections about architectural lighting design we must insist on some very strong moments that have characterized the reflection about lighting and its perceptual function as regards surfaces, volumes and colours within the architecture.

First of all we must get back to James J. Gibson's considerations about visual perception that have represented a basic inspiration for the lighting design theoretical thinking. He reminds us that the fundamental instrument that conditions the exercise of seeing is the "light that is reflected and scattered by surfaces" (Gibson, 1960), this within a "visual space" that is "perceived by virtue of what fills it", "as a continuous surface" or as " an array of adjoining surfaces", a "visual world extended in distance and modelled in depth; its is colored, shadowed, illuminated, and textured, it is composed of surfaces, edges, shapes, and interspaces…and the most important of all, it is filled with things that have meaning" (Gibson, 1950). At this point it is essential to translate the word "light" in the terms of the lighting designer's thinking; light which from the moment it is "reflected and scattered by surfaces" (and colours), that belong to the "visual world" he describes, becomes for us luminance, a central topic around which the practice of the architectural lighting designer gravitates.

Gibson's considerations have been particularly useful to William M.C. Lam, in the occasion of one of the most important investigation conducted by a professional lighting designer about the perceptual comprehension of this discipline, he conducts in "Perception and Lighting as Formgivers for Architecture".

W. M.C. Lam characterises the architectural lighting project with its ability to assign to the architectural environment a supplement of meaning addressing the viewer's "classification of visual stimuli" or "unconscious search for order in the visual field" processes. An important part within the construction of this meaning is held by the viewer's perception of the appropriate distribution of "luminance gradients", according to "shapes", "visual patterns", "contrasts" in "brightness perception" that allow a well balanced and "accurate judgement of colour". Its interaction with human behaviour occurs delivering information from our visual field, from "central" to "peripheral vision", that feed our capability of anticipation regarding our displacement within the architecture which is made of our "expectations", either emotional (through "the affective component of perception"), or functional, filtered through our "experience filter", for it responds to our need to determine the way we will enjoy the architecture, either in a static situation, or as we move across the architecture. (Lam, 1977)

On these basis, and from those reflections that have led to the fact that architectural lighting is a supplement of meaning we lay over the architecture, we have, in some of our previous papers, elaborated the idea that architectural lighting design consists in the distribution of those luminances "on surfaces, colours and objects", in a very similar way to the painter who lays light and shadow over the canvas or the cinematographers complete the idea transmitted by movie images (CarattiZarytkiewicz, 2024). Nevertheless this illustration leave a door opened to further deepening that might reveal its real intrinsic value.

Architecture and the theatre, two different pathways in our mind

The question of the displacement which is understandably not taken in consideration in Gibson's definition of the "visual world" we have previously quoted, appears as inherent to the architecture which is designed for humans who live and move within this "visual space". In order to examine its consequence on the lighting designer's intent, we have chosen a statement by lighting designer Charles G. Stone we usually use as an introduction in front of our students. In an interview he gave

to “Mondo Arc Magazine” he describes the purpose of lighting design either in the architecture and, within or on, the theatre stage, and stimulates our reflection with an inspiring comparison. He points out that: “…The fundamental difference” between theatre lighting and architectural lighting, “is, that in the theatre you sit in a chair and the scene changes in front of you or around you.” and “In architecture you move through the ‘theatre’”. What is said here alludes to two different kinds of attitudes, both of which have an impact on our motor cortex, as a pure mental and imaginary stimulation from the scenographic construction in the first case, and as a consequence of our actual physical displacement within spaces or volumes, among colours, objects, and matters in the context of the architecture, in the second one (Peera *et al*., 2015).
This displacement contributes to the building up of the architecture as a landscape in the user’s mind. This architectural landscape is able to put this mind in order in a comparable way to how Bachelard’s house, “la maison” does it. “La maison” which, for Bachelard, “ is one of the greatest integral force for the thoughts, the memories and the human dreams”, and without which “Man would be a dispersed being”. “The house,” that is “a privileged entity for a phenomenological study of the intimate values of inside spaces, provided that we take it in both its unity and complexity… that furnishes us with disperse images and body of images at the same time.” Within which we are in search “of illusions of stability” we cannot avoid to put in front of W. M.C. Lam “search for order in the visual field” for emotional of functional grounds. (Bachelard, 1997) (Bachelard, 2020)

The imaginary dimension of the lighting stimulus
Within the theatrical perception process, as much as in the architectural one, this mental analysis is cumulatively, or individually, an inner “representation” that is formed in your mind as an idea, the “idea” as an “interior form” (Panofsky, 1989), you elaborate in your mind when you subscribe to the theatre work. This inner image brings together a virtual universe from the lighting, from the scenography, from the script, and the actor’s interpretation. It is the one you build up while you are tracing a mental map of the architecture all along your walking through spaces and volumes (Peera *et al*., 2015). In both cases it is not only the static image as a single sign, the one that, in many cases, would amputate the perceptual process from its spatial content, a dimension brought and sculpted by the architecture which Richard Williams dedicates to “a non-specialized public” (Williams, 2005). It is in fact a more complete one, the one you physically scour moving amid the imaginary stage of the architecture, visually called and stimulated by the quality of the colours and the gradients of luminances, and bringing together functional and emotional information (Cfr. Kandel, 2012), in the building up of a previsional map of your course, from the architectural signs, foreseeing eventual activities.

The production of the right image
This image, either static and unique, or part of what Bachelard calls a “body of images”, is a characteristic of everyday life in the architecture, it is the one we constantly meet in museums or even those where, moving through the architecture, we decide to set in and contemplate, as when we find a cosy corner in an hotel lobby for example. This image is sculpted by lighting and colour that finishes up its meaning, dynamizes its signification, further stimulating our mind, either in a static situation or when we are scouring the architecture as if we were walking along in a succession of movie “shots” and “cuts”(Brown, 2012). Rudolf Arnheim in “Art and Visual Perception” deconstructs and inventories its causes and components as he raises the question of the image. He carefully enumerates and examines all the conditions and all the elements that make up the pertinent image: the balance, the shape, the form as the “…visible shape of content” (quoting the painter Ben Shahn), its growth process, how it stimulates the perception of the space, the role of light, of colour, how it expresses the movement, and dynamics. He describes the processes that make up a pertinent image, in terms of attention catching, by the taking in consideration of the visual dynamic, of the movement and the

shape, delivering a tension, until the reaching of a sense of "restlessness", playing with the viewer's comfort, cheating the common expectations of a symmetric proposal (Fig. 1 & Fig. 2). It is a perceptual exercise of "the experiencing of the visual forces" (Arnheim, 1974), in our case those from the "tectonics" of the architecture (Davies, 2011), of colours, of the light as an energy, and a shape provider, or even as some force able to bring a surprising, but positive, confusion as regards the way we expect to meet the image. All phenomena that consolidate the statement of the message along the path of our scouring of the environment.

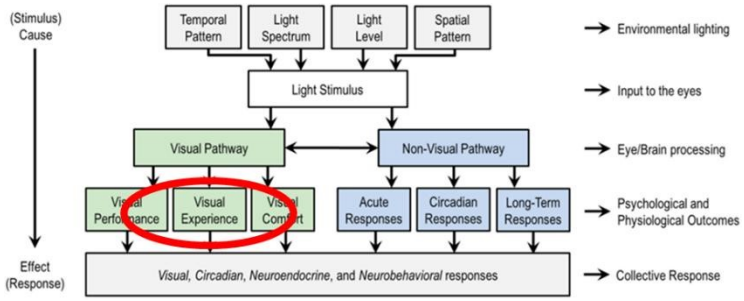

Fig. 1 - An overview of the stimulus (top) response (bottom) relationship between light and human responses

Here we frame the level of the "visual experience" quoted by Houser *et al.* (Fig. 1) (Houser *et al*., 2020), which finds its full development in W. M.C. Lam's notions of the visual "meaning", of the quality of the visual information, that may be exploited by whoever will have to physically and/or visually scour the environment. It is made of Arnheim's "visual forces", that deal with the users prediction of their displacement in the architecture, that's to say with Lam's "attributive classification of visual stimuli", with their "unconscious search for order in the visual field", and either with their "affective components of perception" and/or with their "functional" or "emotional" expectations, then generating an "assignment of meaning", eventually engaging the "beholder's" mind (Kandel 2012), in a very brief treasure hunt in order to finally bring together the whole process, and isolate the final purpose of the whole visual construction (Fig. 2 & Fig. 3).

Fig. 2 – Marie Grosperrin, 2025 Global Designer Master Project, Ecole Bleue, Paris

Fig. 3 – Samuel Beckett's "Oh les beaux jours" 2008, Adriana Asti in Bob Wilson scenography, photo Luciano Romano

The symbolic synthesis of the technical and the aesthetical content.

All these notions, when combined, predispose the set for the reaching of what we have chosen to call "The right image". Such a level of quality in the visual project is only reached in the final phase of the architectural one, once it has laid luminances over the shapes, "surfaces, colours and volumes". This accomplishment, in order to satisfy the material contingencies of the project, now needs to be analysed under a very practical angle of vision like the ritual of the reception by the customer and/or the roped party that has been delegated for this purpose. Their aim, in this occasion, is to check that the normative, the technical, functional and architectural requisites that have been enumerated on the specification booklet have been successfully met. At this point, anyone participating for the first time to this ceremonial would tend to consider that the definitive aesthetical judgement must be excluded from any appreciation, or expected consideration, in front of a whole functional project that could be for example a scientific laboratory or a common office building. But it is not the case. In facts it appears that if all the normative, technical, and functional contingencies may be, as parts of a very precise documentation, technically checked out, the final evaluation of its performance deeply depends on the aesthetic result. Would it only be a question of a simple visual harmony. What apparently only looks like a comforting confirmation of the final result, proves to be in fact the definitive demonstration of the coherence of the project. It is a visual final seal which function is to offer the guarantee of the project congruency as a symbolic statement within the right image, a synthesis between its constructive elements and the deepest emotional expectations of the viewer.

If by any case, on the contrary, any aesthetical incongruency would appear, the contractor's "beholder's" mind, would be left in a state of uncertainty, of an unachieved contractual path. This would unavoidably discredit the lighting design project by throwing on it the veil of the doubtfulness, of a betrayed promise of a symbolic expectation related to the very nature of the light; because the single idea of light, even artificial light, reconducts to the symbolic statement claimed by the natural light, a statement of harmony that has not only established the conditions for the development of human life; but also, and this in the human mind, the conditions of knowledge and wellness, and of the highest expression of virtue. In theses conditions, at the end, the symbolic reaching of a symbiosis between the "beholder's" mind and the project would be dismantled.

The right image as a symbol

The notion of a symbolic situation in this case calls for further explanations regarding the question of the symbol. Thus in order to better frame the choice of such an important word, let's subscribe to Umberto Eco's feeling when in "Semiotica e filosofia del linguaggio", he expresses his discomfort

for the fact that "rarely this term [the word symbol] happens to be defined, relating it *de facto,* to what he calls "an intuitively evident notion" (Eco, 1997), suggesting here, the possibility to generate imprecision. For this reason, in the present case we consider that an accurate description of the notion of symbol is also an important step, as it may consequently reinforce the reflection around how the accuracy of the research of harmony within the lighting and the colour project supported by its technical contingencies.

The etymological origin of the word opens on a very interesting opposition between word "symbol" (from Syn-ballon, σύμβολον), and the Dia-ballon (δίαβολον) that has successively brought to "diabolus", and then "devil" in English, diablo" in Spanish, or "diable" in French, carrying on a negative signification. Taking a closer look to the situation we have previously described, this opposition happens to stand as an accurate representation of the alternative we have presented.

First lets have a look to Syn-ballon which Umberto Eco describes as the putting together of two elements (Eco, 2019). A more extended investigation sends us to the Liddle and Scott dictionary: where Σύμβολον is described as "Each of two halves of corresponding pieces " of a votive object, or a dice, a token of ceramics, which two strangers, "or any contracting parties, broke between them, each party keeping one piece in order to have proof of the identity of the presenter of the other" when they'll be meeting again in the future (Liddle, and Scott, 1996).

These definitions find their confirmation is the synthesis of an abondant literature, beginning with the antique Greece philosophers. For Aristotle the two pieces of a token miss the moment of their bringing together (Aristotle, *Eudemian Ethics*), it is also a contract, a trading agreement, eventually a political synthesis (Aristotle, *Politics*), in "On Interpretation", building up a reflection about linguistics he recognizes the symbol as the manifestation of some states of the mind (here defined as the soul) associating then the symbol to the translation of "what crosses the mind" (Aristotle, *On Interpretation*). In Plato's "Republic" it is a conventional coin that allows the exchange, (Plato *The Republic*), in the "Symposium" he adds the idea of the nostalgy of one portion of the symbol toward the other as each one of them is perpetually in search of the complementary one (Platon, *Symposium*). These elements from the literature corroborate the characteristics of the symbiosis between the normative, technical and functional components of the project and the emotional result of the lighting project in an accomplishment that is finally experienced and symbolized through the way the project's coherence, harmony and aesthetic is perceived by the "beholder" and meet her/his functional and emotional expectations. In this final phase of the project the feeling of a "betrayed promise", the veil of doubtfulness when the expectations are not met anymore and the "symbol" is not reunited, both its technical and aesthetical half miss each other, and we fall in the opposite situation of the Dia-ballon (διαβάλλω), which is divisive, brings discredit, conflict, is associated to calumny (διαβάλλειν, διαβολή), to the intention to cheat, with an uttering an untruthful discourse (Queyrel-Bottineau, 2021).

The reaching of the symbolic synthesis

In the opposite case, from the very moment when the symbolic situation is fully accomplished, the aesthetical impression produced by lighting design takes its place, and what W. M.C. Lam calls the visual "expectation", receives the appropriate answer, as much as its "unconscious search for order in the visual field", and the accomplishment of the" attributive classification of visual stimuli" receives the conditions to perform its duty. The potentially emotional and eventually artistic content the lighting designer brought in the lighting, symbolically melt with the manifestation of the normative and technical instruments that have been used to obtain it.

Conclusions

Those elements of reflection about the elaboration and the accomplishment of the architectural lighting design are useful instruments to build up, in the mind of any student in lighting design, a powerful illustration of the real importance of the architectural lighting design project in front of its main target we have previously dedicated to the building up and managing of the human fundamental well-being". (Caratti-Zarytkiewicz, 2023) (Caratti-Zarytkiewicz, 2024). This duty, finds a pile up confirmation all along the history of the architecture, form the Renaissance re-elaboration of the theoretical thinking of the architecture where a particular attention is paid to "harmony", immanent in the human's mind and body as a microcosm, exactly in the same way is in the macrocosm, or the cosmos (Davies, 2011), as much as in most architects reflections. It is the case of Geoffrey Scott when he writes that "The art of architecture studies not structure in itself, but the effect of structure on the human spirit" (Scott, 1914) , and of Louis I. Kahn as he 1972 defines "well-being" as one of the most important inspirations in the architect's mind (Kahn,1991). From my experience, the role of those illustrations is to definitively conquer large portions of the students minds in order to ensure they will introduce this fundamental target, reflection, or "inspiration", within their own practical, technical, and theoretical reflection. They work as a support to the narration of the project they propose to their customer, in order to bring together and confirm, from various pertinent angles of vision, its consistency and coherence.

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Sensory Lighting and Design: Design Strategies for Multisensory Food Perception in Hospitality Settings

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Abstract

Food perception is a complex and multisensory process, where sight, smell, taste, touch, and hearing interact to create an integrated gastronomic experience. Contemporary culinary experiences rely on this sensory synergy, which influences not only judgments of food quality and freshness but also customer satisfaction and memory of the experience. This article examines the strategic role of sensory lighting and multisensory design in modulating food perception within hospitality environments, with particular attention to interactions among environmental factors, customer expectations, and behavior. Through a critical review of the literature and analysis of emblematic case studies, it explores sensory compensation mechanisms activated under controlled lighting conditions. Under these conditions, the limited availability of visual information leads to an enhancement of gustatory and olfactory perception, generating a more intense and memorable culinary experience. Experimental studies demonstrate that the intentional manipulation of lighting can significantly influence taste perception, dish preference, and length of stay.

Sensory lighting thus emerges as a key design tool to enhance food perception via parameters such as intensity, color temperature, and color rendering. This article also explores the role of materials, surfaces, and tableware in shaping the multisensory environment, thereby contributing to comfort and perceptual quality. The findings highlight how an integrated design approach that considers multisensory perception, sensory lighting, and material choices can substantially improve food perception and customer experience, opening new prospects for the design of engaging environments oriented toward guest well-being.

Keywords: Sensory lighting, Sensory design, Multisensory food perception, Hospitality settings, Lighting design.

Introduction

Over the past twenty years, the hospitality industry has experienced a paradigm shift from a functional focus on service efficiency and product quality to an experiential approach centered on emotional, narrative, and sensory enrichment. Within the so-called Experience Economy, value is co-created through meaning, making environmental design an integral aspect of the product itself (Pine II and Gilmore, 2019). In contemporary dining, the gastronomic experience no longer merely satisfies nutritional needs; it constitutes an immersive cultural event that actively engages all the senses and establishes a dynamic interaction between space, food, and the individual. Consumer neuroscience and sensory research confirm that food perception is fundamentally multisensory, integrating inputs from sight, smell, taste, touch and hearing (Spence, 2015; Velasco *et al.*, 2018; Schifferstein, 2021). Among the environmental factors shaping sensory experience in hospitality contexts—such as restaurants, hotels, and concept spaces—lighting stands out as a crucial design element. As the first stimulus perceived on entering a space, lighting shapes cognitive expectations that influence how the brain processes olfactory and gustatory cues. Psychophysical studies demonstrate that even minimal variations in light intensity (±50 lx) or color temperature (±500 K) can modulate taste perceptions such as sweetness, acidity, or freshness to a degree comparable to actual modifications in the dish's composition (Wang *et al.*, 2022).

In this context, lighting becomes a strategic design tool that modulates the perceptual identity of food without changing its nutritional composition, indirectly affecting customer behavior and satisfaction

(Biswas, Szocs and Abell, 2019). However, much research has focused on isolated sensory variables, such as illuminance, often neglecting their synergy with tactile materials, acoustics, and brand storytelling. This gap underscores the need for an integrated methodological framework to guide designers and entrepreneurs toward a coherent synthesis of perception, well-being, and narrative identity. Addressing this need, the present article adopts a critical, multidisciplinary approach to investigate how sensory lighting influences gustatory and hedonic perception. It emphasizes the interplay between environmental factors, customer expectations, and behaviors. Through a review of relevant literature and the analysis of emblematic case studies, the study explores sensory compensation mechanisms activated in environments with reduced or targeted lighting, laying the foundation for a lighting design model oriented to multisensoriality. Here, sensory lighting transcends mere visibility and functions as a powerful expressive and psychophysiological medium that elicits emotional, cognitive, and behavioral responses. In hospitality settings, it emerges as a key design dimension that shapes food perception, affects duration of stay, and defines the identity of the gastronomic experience (Spence, 2015). Positioned at the intersection of sensory neuroscience, color theory, and environmental design, this contribution aims to propose innovative strategies for the future of experiential design in hospitality.

State of the Art: Neurobiological Mechanisms and Sensory Compensation

Food perception is a multisensory process that integrates sight, smell, taste, touch, and hearing to create a coherent gastronomic experience. Recent neurogastronomy studies indicate that up to 80% of flavor perception derives from sensory inputs beyond taste, such as vision and olfaction, processed in brain regions including the orbitofrontal cortex and amygdala (Kringelbach, 2005; Lee and Spence, 2022; Guedes *et al.*, 2023). Visual cues—color, brightness, food presentation—shape taste expectations before tasting, while auditory stimuli also influence perception, with harmonic sounds enhancing sweetness and metallic tones increasing bitterness (Spence, 2015). Notably, higher light intensity tends to amplify perceived flavor intensity (Johansson, Kelber and Ulrich, 2024). A central mechanism is sensory compensation: when one input is limited, others are heightened. In low light, gustatory and olfactory sensitivity increase, intensifying taste awareness and fostering an immersive dining experience (Delwiche, 2012; Spence, 2022). Sensory lighting design thus goes beyond aesthetics to actively modulate brightness, focus, and spatial distribution, orchestrating how diners see, taste, smell, and remember food. This understanding guides the creation of immersive gastronomic spaces integrating light, materials, sounds, and scents for enhanced perceptual richness.

Technical Parameters of Sensory Lighting

Effective sensory lighting design in hospitality requires precise control over several technical parameters that shape diners' multisensory experiences and influence food perception. Key parameters include correlated color temperature (CCT), color rendering index (CRI), light intensity, spatial distribution and directionality, and circadian metrics such as the Circadian Stimulus (CS). Lighting is best implemented using a layered approach combining ambient, task, and accent lighting, which differentiates spatial zones and activates targeted perceptual effects. For example, maintaining CS below 0.2 in the evening aligns lighting with human circadian rhythms, promoting relaxation, improved digestion, and social interaction (Rea and Figueiro, 2018). Tunable white LED technology allow independent adjustment of photopic illuminance (lux) and melanopic components (CS), , enabling calibration of lighting conditions for both visual appeal and biological compatibility. Experimental research shows that dim lighting under 100 lux activates sensory compensation mechanisms and can increase perceived sweetness by 10–20% (Boman, 2021). Low illumination also encourages relaxation, slows cognitive processing, and extends diners' length of stay and satisfaction (Wansink and van Ittersum, 2012; Biswas, Szocs and Abell, 2019). Brighter environments above 400 lux are better suited to dynamic or fast dining contexts.

Color temperature plays a significant role in gastronomic perception. Warm CCTs (2700–3000 K) evoke feelings of intimacy and comfort by enhancing golden, warm hues characteristic of foods like bread and meat. In contrast, neutral CCTs (3000–4000 K) enhance sharpness and perceived freshness, ideal for vegetables and fish (Burkert, Schaufler and Voigt-Antons, 2022; Nanjundappa *et al.*, 2023; Velasco *et al.*, 2023). This effect is reinforced by the psychothermal association of warm colors with heat and hospitality, and cool colors with freshness and lightness.

CRI measures a light source's capacity to render colors authentically; a CRI above 90 is recommended in culinary settings to ensure food appears natural and appealing (Nazarenko *et al.*, 2024). Advanced metrics like the TM-30 Color Fidelity Index (Rf) and Gamut Index (Rg), which consider a broader range of samples, offer more precise assessments of color rendering and saturation. An Rg near 100 maintains natural hues, whereas values above 110 increase saturation, potentially enhancing vividness at the cost of naturalness.

Moderate increases in spectral saturation have been shown to improve quality perception. For instance, enhanced saturation can heighten the perceived freshness of sushi without reducing natural appearance and boost the sweetness of desserts like strawberry mousse (Spence, 2015; Liu *et al.*, 2022). Light color also exerts strong sensory and emotional influences Red and yellow lighting typically enhance appetite and satisfaction, while blue light tends to decrease consumption inclination (Küller *et al.*, 2006; Özkul, Bilgili and Koç, 2020). Synesthetic effects occur in contrasts between container and content; for example, a dessert on a white plate under warm light is perceived as sweeter than the same dessert served on darker containers (Piqueras-Fiszman *et al.*, 2012; Spence, Piqueras-Fiszman and Blumenthal, 2014). Green light can reduce perceived waiting times and promote calmness, offering strategic advantages in managing guest experience (Özkul, Bilgili and Koç, 2020).

Spatial aspects such as contrast and luminance uniformity (U_0) are vital for visual legibility and valorization of food. Balanced luminance ratios—such as a 3:1 plate-to-background ratio—effectively guide viewers' attention (Arce-Lopera *et al.*, 2012). Ideal uniformity values range between 0.5 and 0.7; values below 0.4 create visual heterogeneity, while values above 0.8 flatten depth perception (Abboushi *et al.*, 2023).

Directionality and beam angle of light also impact perceptions of freshness, texture, and appeal. Narrow beams (<15°) accentuate crispness, while wider beams (>40°) soften the appearance. Techniques like grazing light (5–10°) on textured surfaces enhance tactile anticipation (Ho, Landy and Maloney, 2006; Niu and Lo, 2022), whereas soft wall-wash lighting creates neutral backdrops ideal for balanced spatial perception (El-Nasr and Rao, 2004).

In summary, sensory lighting parameters extend well beyond basic visibility, deeply influencing multisensory perception, emotional responses, and the rhythm of hospitality experiences. Designing effective sensory lighting requires shifting from purely photometric approaches toward integrative, calibrated strategies that stimulate gustatory expectations and support immersive dining environments.

Synergies between Touch, Surfaces, Materials, and Lighting in Hospitality

In hospitality settings, the quality of the sensory experience critically depends on the integrated synergy between lighting systems, material surfaces, and tactile stimuli. The interaction between visual and tactile perception influences not only aesthetics but also psychophysiological well-being, perceived comfort, and overall satisfaction. Specular materials such as glass and polished metals enhance light reflectance and contrast, improving spatial depth cues and perceived freshness of food (Abboushi *et al.*, 2023). Diffuse and textured materials—such as untreated wood, ceramics, and natural fibers—softly scatter light, creating warm and intimate atmospheres. Directional lighting accentuates surface textures, evoking tactile sensations even without physical contact (Ho, Landy and Maloney, 2006). The choice of materials for tableware and furnishings contributes to the multisensory environment: glossy or white ceramic surfaces amplify food color fidelity, while colored or matte

finishes influence spectral saturation and thus taste appreciation (Velasco *et al.*, 2015; Wang *et al.*, 2020). The tactile quality of objects (smooth or rough) modulates sensory satisfaction and conveys impressions of quality or authenticity (Guberman, Sakdavong and Galmarini, 2025). The optimal fusion of materials and lighting measurably influences both physiological and emotional domains, fostering social interaction, extending temporal engagement, and enhancing overall satisfaction levels. In summary, sensory lighting is a complex, non-isolated factor that operates synergistically with spatial materiality, producing crossmodal correspondences that potentiate multisensory integration and elevate the perceptual value of the gastronomic experience.

Case Studies: Innovative Implementations of Multisensory Design

The role of sensory lighting and integrated multisensory design is increasingly evident in prestigious hospitality projects, where light actively shapes taste perception, enhances mood, and engages guests through orchestrated sensory environments.

Ultraviolet (Paul Pairet, Shanghai): An Icon of Immersive Multisensory Dining

Ultraviolet represents one of the most advanced examples of multisensory orchestration applied to gastronomy. Operating from 2012 to 2025, the restaurant revolutionized dining by synchronizing each course with meticulously choreographed lighting, projections, soundscapes, and aromas. For instance, a tropical dessert was served under orange lighting paired with exotic sounds, while a seafood appetizer featured deep blue light, aquatic sounds, and iodized scents. This approach, defined by Pairet as "psycho-taste," combines cognitive suggestion, memory, and synesthesia to amplify gustatory perception through total sensory orchestration (Yemsi-Paillissé, 2020). Dishes were never presented in isolation but embedded within immersive sensory choreography, transforming meals into holistic emotional and cognitive experiences. Neuroscientific research supports that gustatory perception is profoundly modulated by multisensory contexts, particularly visual, auditory, and olfactory cues (Small and Prescott, 2005).

Academic studies describe Ultraviolet not simply as a restaurant but as an experiential art installation capable of producing a unique sensory and cognitive journey (Yemsi-Paillissé, 2024). In this context, light functioned as an active narrative and cognitive medium, both immersive and emotional, modulating the perceptual identity of dishes in real time. Ultraviolet thus exemplifies a paradigmatic model of multisensory lighting direction, integrating lighting design into an advanced experiential strategy that exploits synesthesia and crossmodality to generate enhanced psycho-gustativity.

Kitchen Theory (Jozef Youssef, London): Applied Synesthesia and Experimental Lighting

Kitchen Theory is a unique experimental hub integrating sensory science, design, and art to produce immersive multisensory experiences. Collaborating with the Crossmodal Research Laboratory at the University of Oxford, it explores empirical links between environmental stimuli and taste perception, focusing on light–color–flavor interactions. Two emblematic tasting menus, Synaesthesia (2015) and Náttúra (2021), are paired with carefully designed sound, light, scent, and material environments, with lighting serving as a primary stimulus that evokes emotions, guides gustatory expectations, and modulates overall sensory perception. Lighting functions not only as illumination but as an "invisible seasoning," shaping the anticipatory experience prior to tasting. Tailored light color and intensity profiles are semantically aligned with dish typologies and sensory narratives. Warm hues such as red and orange enhance perceived sweetness and aromatic intensity, while cool hues like blue and green diminish hedonic value and salinity perception, effectively steering taste expectations and emotional states (Spence and Youssef, 2019). Lighting also directs attention and structures the dining rhythm through layered illumination—ambient, scenic, and spot—accentuating texture and chromatic composition. These effects are validated empirically through controlled experiments measuring subjective and behavioral responses. Additionally, diners actively participate as co-creators of the narrative, with interactive and responsive lighting guiding focus and meal time. Kitchen Theory

presents an advanced and replicable empirical framework for multisensory lighting design, providing protocols for chefs, designers, and researchers to systematically optimize sensory dining experiences.

Alinea (Grant Achatz, Chicago): Theatrical Multisensory Dining

Alinea, led by Grant Achatz, sets a standard in multisensory haute cuisine, where lighting plays a crucial theatrical role in the performative dining experience. The dining room becomes a stage where each course serves as an "act," introduced with rituals to surprise and captivate diners. Each course functions as an artistic "act," guided by lighting that directs visual focus and enhances flavor perception through deliberate changes in hue, brightness, and spatial arrangement. Iconic examples like the Paint Dessert—an edible artwork created live at the table—are elevated by sophisticated lighting effects that boost color saturation, texture, and depth, deepening sensory engagement. Warm-toned lighting used for sweet courses acts as an anticipatory cue aligned with predictive coding models, reducing cognitive dissonance and amplifying perceived sweetness. These cues show how lighting not only improves aesthetic appeal but also plays a functional role in shaping the emotional flow of the meal and encouraging active sensory participation from guests. Research confirms that brightness, chromatic tone, and how light is spread out significantly influence how food is perceived. Alinea's experience combines choreographed interventions, visual illusions, and multisensory interactions across olfactory and tactile senses, surpassing traditional food presentation and creating coherent, immersive gastronomic stories. It stands as a globally influential model of artistic and lighting-driven multisensory gastronomy (Spence, 2019; Jones and Cain, 2023).

Conclusions

The findings confirm that sensory lighting surpasses mere functionality to act as a strategic design lever capable of modulating food perception and enhancing hospitality experiences. Conceived as a narrative medium, light guides expectations, amplifies flavor perception, and embeds sensory memory. Case studies such as Ultraviolet, Kitchen Theory, and Alinea demonstrate how lighting, materials, sound, and scent converge to create coherent and memorable experiential environments (Spence, 2022). From a technical perspective, the deliberate use of parameters like correlated color temperature, advanced color rendering indices, directionality, uniformity, and luminance ratios enables activation of crossmodal correspondences and calibration of food's perceptual identity without altering its composition. The literature also highlights the importance of non-visual dimensions of light, including circadian-aligned metrics that enhance guest comfort and dining quality (Rea and Figueiro, 2018; Royer, 2022). Future directions point to adaptive, personalized lighting environments dynamically modulated by AI and IoT systems based on guest profiles, menus, and timing, harmonizing biological rhythms with chromatic fidelity and brand identity. Ethical considerations including transparency, privacy, and informed consent are crucial in these emerging applications (Florido-Benítez and del Alcázar Martínez, 2024).

Concurrently, advances in experiential prototyping—such as digital twins and augmented/virtual reality platforms—facilitate predictive testing of multisensory scenarios before real-world implementation. These tools support iterative refinement of visual and circadian parameters while enhancing energy efficiency (Mohammadrezaei *et al.*, 2024; Yeom *et al.*, 2024).

Overall, sensory lighting design is evolving toward neuro-centered, data-driven ecosystems, where light acts as an interface among physiology, emotion, and culinary narrative. Food and tableware serve as dynamic sensory displays, while design takes on an ethical mediating role balancing personalization, health, and cultural identity. This paradigm shift reconceives the lighting designer's role from visual director to orchestrator of a holistic sensory ecosystem with technical, scientific, and cultural responsibilities.

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Considerations about light and colour for human beings in microgravity conditions

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Abstract

The race to long-term space missions beyond Earth's atmosphere requires a deep understanding of how environmental factors, such as light and colour, affect human physiology and psychology in microgravity. While microgravity has been extensively shown to compromise multiple aspects of human health, including the musculoskeletal and ocular systems, its impact on visual perception, specifically colour perception, remains an area of limited investigation. This paper outlines the current state of research, highlighting the need for dedicated studies on the perceptual and physiological responses to light and colour stimuli in microgravity.

Existing studies indicate that microgravity significantly alters the integrity of the human body. Visual stimuli have been proposed and tested as countermeasures against space-induced stress in simulated space station environments. For instance, studies using the Delphi method have investigated how colour schemes can mitigate stress in confined hygiene areas within space habitats. Additionally, short-duration simulated spaces have been used to test multicoloured lighting environments and explore their psychological effects on participants, aiming to enhance well-being and performance.

Other approaches have directly examined visual perception in microgravity through parabolic flight experiments, which simulate weightlessness for brief periods, or through postural techniques that emulate gravitational unloading. These methodologies provide insight into the human visual system's adaptability but are limited in their duration compared to long-term missions.

Although no direct empirical data currently confirm changes in colour perception during extended space missions, ophthalmological studies have documented physiological alterations due to microgravity, including optic disc oedema, globe flattening, choroidal folds, and hyperopic shifts. These effects suggest possible impacts on retinal and cortical processing, yet astronauts have not self-reported changes in colour perception. This discrepancy raises questions about compensatory mechanisms, such as chromatic constancy and contrast adaptation, which might preserve perceptual stability despite physiological changes.

Furthermore, distinguishing the intent of colour sensitivity assessments is critical. The context in which colour perception is evaluated, such as the observed environment, can trigger compensatory cognitive or physiological mechanisms that play a vital role in interpreting the results.

Given the absence of evidence indicating altered colour sensitivity in space, it is plausible that the physiological mechanisms underlying circadian entrainment via light at specific wavelengths remain functional in microgravity. This hypothesis supports the continued application of light-based interventions for circadian regulation in extraterrestrial settings. However, targeted research is essential to verify this assumption and optimise lighting design for future long-duration missions.

Keywords: Colour, Lighting, Microgravity, Physiology, Psychology.

Introduction

Staying in confined and isolated environments, such as space stations, requires numerous precautions in the design of living spaces. In these places, microgravity and the context - so different from the one in which we evolved - have proven adverse effects on the quality of life of astronauts (from a psychological and social point of view) and on their physiology, introducing a series of deteriorations that put a strain on their bodies. Astronauts are, in fact, faced with factors such as the lack of spatial and temporal references, induced by the removal of the normal cycle of day and night and life in microgravity conditions.

The individuals who participate in these missions are trained for a long time and possess excellent preparation both physically and mentally, however, despite this, microgravity induces a series of changes to their body that lead them to experience a series of systemic problems such as variations in intracranial pressure that can lead to the SANS - Spaceflight-Associated Neuro-Ocular Syndrome (Rodrigues, Russomano and Santos Oliveira, 2025), muscle atrophy, reduces bone density, muscle tone loss; bodily fluids shift, changes in blood volume, cardiovascular issues, DNA damage and disruptions to sleep-wake cycles. All these issues are under constant review (Ray, Parvez and Islam, 2025), with more ambitious missions in mind (such as Moon permanent outposts, tourist space stations or Mars exploration).

In space stations, moreover, numerous variables generate strain, the so-called *stressors*, capable of creating problems for the crew, as much as, if not more, physiological problems. For example, the perception of a decline in care provided by individuals outside the crew (Bell et al., 2025) or numerous other issues related to astronauts' mental health status (Smith, 2022). Mood and time orientation during the day, together with the regulation of the sleep-wake cycle, are very important factors; These are not exclusively psychological factors (they are also physiological), but the relapse of these problems can be significant from a psychological point of view. In this context, the use of light and colour can help improve the psychophysiological conditions of the crew, following design measures commonly called Human-Centric Lighting. All these procedures play a strategic role, as they directly influence alertness, mood, spatial orientation and cognitive performance (Cajochen *et al.*, 2005).

Despite the growing awareness of the relevance of these aspects, the scientific literature typical of these spaces is biased towards the study of critical factors related to operational safety (e.g. effects of CO_2 levels (Garbino *et al.*, 2024), risk of fire (Guibaud *et al.*, 2022), energy storage (Sharma and Santasalo-Aarnio, 2025), shielding from cosmic radiation (Li *et al.*, 2025), ecc.) In other words, there is an obvious focus on immediate and potentially catastrophic hazards with respect to psychophysiological aspects, such as colour perception, light quality, or the overall sensory experience of the habitat.

In 1988, NASA conducted extensive research on human factors in space design (Wise and Wise, 1988), analysing over 200 articles that dealt with colour and man in various aspects of their interaction. This review resulted in a number of interesting considerations related to the design of the spaces, such as:

- The practice of avoiding decisions based on preferences/taste. Because there are too many variables to keep in consideration;
- Allow personal choices on colour for the astronauts, to promote a «sensation of being in control»;
- Use colour always for his readability and meaning (like red/green), but never for aesthetic choice;

- Visual mechanisms (Purkinje shift, colour constancy, and the position of rods and cones on the retina) must be taken into account and, if possible, used to improve the readability of the environment.

These and other considerations have proved helpful in the choices for the construction of extra-atmospheric living spaces. Still, the studies considered almost all referred to the regular interaction between man and colour. Microgravity is not considered, and therefore, a natural question to ask is: In microgravity, does our perception of light and colour vary? And if it does vary, does it affect our choices and habits? Are adaptation strategies applied? The research that addresses these questions is unfortunately not as extensive as that considered by NASA during its colour review; however, some research can provide interesting food for thought.

Simulated and Analog environments

Space stations today are primarily occupied by laboratory facilities, where astronauts conduct numerous tests to evaluate as many study parameters that form the basis of space exploration. In addition to the physical conditions they have at the beginning of the mission, astronauts must maintain excellent psychophysical performance to conduct the numerous tests required at space stations. In addition, they must be able to respond quickly and effectively to adverse and unexpected conditions. The various physical problems we mentioned earlier are partly counteracted by physical exercise.

To predict the perception of space, also from a psychological point of view, an approach often used is that of simulated environments. Realistic mock-ups of space station spaces are created, and subjects are used to evaluate their reactions under certain conditions. Isolation experiments such as the *Mars500* (Basner *et al.*, 2013), in which a group of volunteers lived for 520 days in a complex that simulated a station on Mars, or the *Human Exploration Research Analog (HERA)* of NASA (NASA, 2025), which is intended to pave the way for bases on the Moon and Mars.

Simulated spaces, moreover, are not only isolated mockups in which subjects are locked up for a given period of time, but also places on Earth that, due to their characteristics, are considered *Terrestrial analogue sites*. Places whose unusual conditions (such as the presence of specific microorganisms, extreme thermal conditions, etc.) make them particularly desirable for this type of research. Some mock-ups of space stations or laboratories where these factors are studied are built in places such as the Palmer and McMurdo stations in Antarctica, precisely to simulate portions of the mission, to discover how human health reacts to adverse conditions, to accelerate the development of countermeasures, and to develop new technologies. However, the fundamental problem remains that, even when these mock-ups faithfully simulate the spaces of space stations, microgravity is not taken into account in many cases.

There are mainly three approaches to simulate microgravity:

- *Water immersion* – which, however, requires specific equipment and is not optimal for simulating microgravity in the interiors of space stations;
- *Head Down Bed Rest (HDBR)* – an approach that involves having rest sessions on an inclined plane. A setting that wants the subject's head lower than the rest of the body, in order to have a displacement of fluids that induces the *sensation* of microgravity, as in tests VaPER of 2017 (Clément *et al.*, 2022) and AGBRESA of 2019 (Frett *et al.*, 2020);

- *Parabolic Flight* – a method that allows for remaining in microgravity conditions for a short time, around 20 seconds. A colour perception test using this method will be described in the next section.

With regard to colour perception, we can mention studies conducted in simulated environments, such as virtual reality. In a 2023 study (Jiang *et al.*, 2023), the researchers tested the visual tracking ability on 54 subjects (non-astronauts) using the HDBR method, with an inclination of 12° for short periods of time (three hours) instead of very long periods as those used at NASA (30 days for VaPER and 60 days for AGBRESA) and this was done to reduce the time of the experiment. During the various phases of the test, the subjects observed simulated environments (the International Space Station ISS and the Chinese "Tianhe" station) using a virtual-reality headset. The colours used were very saturated, and what the researchers verified was the visual strain and eye tracking ability of the subjects. The study concluded that HDBR (and possibly microgravity as well) affected the subjects' tracking ability and suggested that cool colours made tracking more effective and less effortful than warm colours. The study, however, presents some points that could be further improved: it was conducted with a very pronounced inclination and in a short time, the subjects, were not astronauts and the environment was virtual; in such a context, only physiological parameters can be considered, while psychological parameters might be too influenced by factors that can compromise the real response of individuals (no EEG or ECG were administered). Moreover, the colours used were highly saturated, and their use in extreme conditions, such as those of a space situation, must be carefully evaluated because saturated colours can affect arousal (Wilms and Oberfeld, 2018). The study does not dwell on changes in colour perception in microgravity states simulated by HDBR.

Despite the unanalysed aspects, the study by Jiang and colleagues used a fundamental approach in trying to frame the problem, namely the attempt to recreate microgravity. In a previous study (Jiang *et al.*, 2020), the themes of light and colour in the spaces of space stations (sanitary area) were explored, but the microgravity factor was excluded entirely. In this type of work, research is conducted in a simulated space on the choices of subjects (who were also not astronauts) and on the psychological aspects induced by the colour within it. The reconstruction of a mockup, even if it is extremely faithful within a space station, still lacks the microgravity factor. This can introduce an unquantifiable discrepancy between the results obtained and those that astronauts might experience in real-world contexts. It is not difficult to imagine that simulations conducted in Earth-based environments share this crucial point. However, some studies have sought to address this problem by inducing a perception of microgravity with HDBR.

Parabolic Flight

Parabolic flight allows microgravity to be simulated on board an aircraft for short periods (20-25 seconds). The aircraft performs a bell-shaped flight at the peak of which the trajectory cancels out gravity. In this brief period, the perception of microgravity is identical to that experienced permanently on space stations.

There are not many studies in the literature that have addressed light and colour during parabolic flight. *White's* work on the effects of temporary weightlessness on the perception of contrast certainly paved the way (White W. J., 1965), as did *Kitayev-Smik's* on colour perception and saturation (Kitayev-Smik L. A., 1972). Even more recently, attempts have been made to highlight how microgravity can affect colour perception using parabolic flight (Schlacht, Brambillasca and Birke, 2009). Anche il test di *Schlacht* e colleghi sembra confermare l'esistenza di alcune modifiche percettive.

However, some considerations on these results must be made. According to White's results, our visual system appears to reduce the contrast required to discriminate a target, especially at low luminance levels. With regard to colour, *Kitayev-Smik* points out that, while highly saturated yellow and red are perceived with the same brightness, blue tends to appear darker and colours obtained by the sum of tints (yellow-blue), instead of green, tend to be classified as yellow. The test conducted by *Schlacht* and colleagues also reported differences in chromatic perception; the colour results differ from those of *Kitayev-Smik*. In the most recent paper, blue was more distinguishable than red, and an increase in perceived saturation in yellow was observed. The results also seem to confirm a general reduced sensitivity to luminance. The reasons for these results could be sought in the modified blood supply to the retina or in a possible change in the shape of the lens due to the sudden change in gravitational conditions. As early as 1963, *White and Monty* described the visual deficits resulting from large accelerations (White and Monty, 1963).

Parabolic flight tests have a disadvantage due to the very nature of the test, namely, the issue of statistical significance. It is not possible, for practical reasons, to conduct the test on numerous people, as these flights usually have a limited number of passengers. In addition, the cost of the experiment itself limits its repeatability over large numbers. However, the results obtained in these studies are significant, as they show that variations in gravitational conditions lead to changes in chromatic and luminous perception. However, a consideration must be made regarding a factor that *Popov and Boyko* had already expressed in a research on *Parabolic Flight* (Popov, V. and Boyko, N., 1967): our visual system is able to put in place mechanisms to compensate for the effects of unexpected changes, such as, for example, chromatic constancy in simultaneous contrast.

If the information we obtain from these tests is seen in preparation for colour design in environments where microgravity is the normal and permanent condition, we cannot fail to take into account the corrections that are applied automatically and continuously by our brain, effects such as chromatic adaptation over time (Gupta *et al.*, 2020) or even adaptation to extraordinary conditions such as the reversal of the field of vision (Sachse *et al.*, 2017). While the visual system responds to changes in gravity, this does not guarantee that such changes can be felt over a prolonged period.

Pre- and post-mission clinical analysis

Another interesting approach to evaluating microgravity on light and colour is the one presented by Mader and colleagues (Mader et al., 2011), in which clinical tests were conducted on seven astronauts at departure and after six months of the mission on the space station. The test clearly highlighted the adverse effects of microgravity on the subjects' bodies. Clear signs of damage to the eye appeared: optic disc oedema, globe flattening, choroidal folds, cotton wool spots (CWS), nerve fibre layer thickening, decreased near vision and hyperopic shifts. In addition, the authors administered a questionnaire to 300 astronauts returning from missions (long or short), after which 29% reported losing visual acuity at a distance and 69% at near. In many cases, the damage has been proven to be irreversible. Of the seven astronauts who underwent a medical examination, none complained of any noticeable decrease in the ability to perceive colours.

These results could be consistent with the brain's correction of visual perception described in the previous paragraph. It is difficult to prove that astronauts did not, in fact, undergo any change in colour perception; however, within six months, even if there was one, it could have been dulled by the cognitive mechanisms of our visual system.

Anonym expert consensus

In a 2022 study, *Jiang's* group of researchers reanalysed the health area of space stations (Jiang *et al.*, 2022), which is rightly recognised as one of the areas that can induce the most stress in the astronaut crew. In this case, microgravity was not simulated using HDBR or a reconstruction of space; instead, a Delphi study approach was used. This type of method is significant when the material on the subject is scarce, or not in agreement, or the organisation of meetings or tests is not favourable or practicable. After a careful initial selection phase, the authors identified a pool of 30 experts with over 10 years of experience, including colour designers, colour-measuring experts, space engineers, and astronaut trainers. The experts were called upon to evaluate the colour palette for the design of the stool and urine disposal area, the negative-pressure machine, and the control interface (waste and decompression machine). The primary stressors recognised for this area were: confined space, odours, time of use, operational complexity, and, of course, environmental colour.

The experts, independently and over ten weeks, without confronting each other, formulated hypotheses and chose colour palettes based on the most pertinent observations from their experience. The authors collected the responses, qualitatively and statistically analysed them, identified convergences and outliers, and produced a summary report that was sent to the experts. The latter can see the results (anonymous) and decide whether to revise or modify their proposals based on them. This iterative process, managed by the authors, leads ideas to converge naturally, and anonymity allows experts to maintain independent judgment, avoiding biases arising from authority or the recognition of dominant hypotheses due to expert hierarchy.

This process led to the identification of a valid solution for the chromatic aspects of the health area of the space station, specifically, for the environments with hygienic devices, a palette of light colors (blues, greens and grays) with low saturation was chosen, while for the operational interfaces, the choice fell on bright and high saturation colors (red, yellow, green and blue) used only locally to increase the readability of the instructions without causing visual overload.

Conclusions

In this article, we observed some of the procedures used by researchers to evaluate the interaction between light, colour, environment, and human beings in the context of research on microgravity for the design of future possibilities in space exploration.

Obviously, the best choice for conducting this type of research would be to execute the tests directly on the space stations, assessing individuals' psychological and clinical conditions at the beginning, during, and at the end of the mission. However, the evaluation of the psychological impact of colour (which can be distorted by its reduced perception) is not commonly taken into account in the tests described in the literature.

The use of various shades of white light (Correlated Colour Temperature) is already employed in an extra-atmospheric environment; the principles of Human-Centric Lighting (HCL) are nevertheless proving valid. However, it should be emphasised that the channel that leads to physiological regulation (used by HCL) is non-image forming and does not imply vision (and consequently, the meaning of what is observed that leads to psychological response), which instead follows a different path in our body (Siniscalco, Bortolotti and Rossi, 2022).

A test to evaluate the perception of light and colour in the context of microgravity should therefore be scalable, depending on the available resources. Simulated spaces (where, possibly, techniques such as HDBR are used) should allow for as quantitative an assessment of discrepancies as possible, using

tests on validated samples, such as the *Farnsworth-Munsell* (Farnsworth, 1943), or tools such as the anomaloscope, to determine whether it is possible to detect changes in perception.

Another essential precaution would be not to limit the evaluation of feedback to the questionnaires administered to the subjects, but to involve a group of experts, who, similarly to what was described in the Delphi study, can interpret the results and suggest solutions to any critical issues. Multiple considerations by experts from various fields of the gathered data might allow the researchers to evaluate many aspects that a single specialised team might not notice easily.

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The role of time arrows in colour perception

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Abstract

The concept of temporal asymmetry, embodied in the various arrows of time, constitutes a fundamental framework for understanding irreversibility and directionality in natural processes. This review synthesizes interdisciplinary insights into how three principal arrows of time—the thermodynamic, psychological, and cosmological arrows—intersect with and inform the mechanisms underlying human colour perception. The thermodynamic arrow, grounded in entropy's irreversible increase, manifests materially in pigment degradation and the entropic constraints on biological visual systems, thereby shaping the temporal stability and evolution of perceived colours. The psychological arrow, reflecting the unidirectional flow of subjective experience and memory, modulates chromatic perception through temporal context, sequential processing, and culturally embedded chrono-colour associations. Meanwhile, the cosmological arrow situates colour perception within the expansive temporal framework of the universe's metric expansion, influencing scientific interpretations of colour via cosmological redshift and informing aesthetic representations of cosmic time. Through a comprehensive review of physical principles, neurocognitive processes, and cosmological phenomena, this paper elucidates the intricate and traditionally grounded role of temporal directionality in shaping colour perception, advancing a multidisciplinary dialogue that integrates physics, psychology, and perceptual science. The findings underscore that colour perception is not a mere instantaneous sensory event but a temporally embedded phenomenon, conditioned by fundamental physical irreversibilities and the experiential flow of time.

Keywords: arrow of time, colour perception, thermodynamic irreversibility, psychological time, cosmological expansioncolor.

Introduction

The concept of the arrow of time, first articulated by Sir Arthur Eddington in the early 20th century, has long been fundamental to our understanding of temporal asymmetry and irreversibility in the physical world. Traditionally associated with the unidirectional increase of entropy as dictated by the Second Law of Thermodynamics, the arrow of time reflects a preferred temporal orientation that distinguishes past from future. Over the decades, this concept has expanded beyond physics, encompassing psychological and cosmological dimensions that collectively define the multifaceted nature of temporal directionality. While extensive research has elucidated the role of time's arrows in physical phenomena and human cognition, their influence on sensory perception—particularly colour perception—remains relatively underexplored.

Colour perception is typically approached as an immediate, spatially determined process governed by optical physics and neurophysiology. However, emerging interdisciplinary perspectives suggest that temporal asymmetries embedded in the arrows of time subtly shape how colour is experienced, remembered, and interpreted. The thermodynamic arrow, through the irreversible degradation of pigments and optical media, imposes a temporal context on physical chromatic stimuli. The psychological arrow influences the sequential and predictive aspects of chromatic processing, embedding colour perception within the flow of human consciousness and memory. Meanwhile, the

cosmological arrow situates colour in a grander universal framework, where phenomena such as cosmic redshift link colour perception to the expanding universe and the history of light itself.

This review synthesizes current knowledge on the thermodynamic, psychological, and cosmological arrows of time, and examines their combined and individual effects on colour perception. By integrating perspectives from physics, neuroscience, psychology, and cosmology, the paper aims to illuminate how temporal directionality not only grounds but actively modulates chromatic experience. In doing so, it seeks to enrich the theoretical foundation of colour science and highlight avenues for future research into the temporal dynamics that underlie one of humanity's most fundamental sensory modalities.

1. Arrow of time: Definition

The arrow of time denotes the unidirectional flow and intrinsic asymmetry of temporal experience. First formalized in 1927 by Sir Arthur Eddington, it posits a preferred orientation in time grounded in entropy's irreversible increase. Eddington argued that this temporal vector, evident in the progression from order to disorder, could be inscribed within the four-dimensional spacetime continuum—his "solid block of paper"—thus embedding irreversibility into the fabric of the cosmos. Despite its conceptual longevity, the arrow of time remains a central puzzle in physics, revealing a disjunction between reversible microdynamics and irreversible macroscopic phenomena (Weinert, 2004).

Since antiquity, humanity has sought to elucidate two primordial phenomena: the origin of the cosmos and the advent of life. Contemporary discourse increasingly suggests that both may be integratively apprehended through the metaphor of the arrow of time (Altekar, 1998).

2. Arrows of time

The notion of the "arrows of time" encompasses the distinct manifestations of temporal directionality observed in nature, notwithstanding the near time-reversibility of the fundamental physical laws. Conventionally, three principal arrows are delineated, each rooted in foundational tenets of classical and contemporary physics. While no canonical enumeration of the "arrows of time" exists, a plurality of physicists and philosophers acknowledge multiple, conceptually distinct temporal asymmetries—typically ranging from three to six, with some taxonomies extending further. Among the most widely recognized are: the thermodynamic arrow, characterized by entropy increase; the psychological arrow, reflecting the unidirectional structure of human temporal perception; and the cosmological arrow, associated with the universe's metric expansion. Additional frequently cited arrows include the electromagnetic arrow, the quantum measurement arrow (pertaining to wavefunction collapse), and the particle decay arrow.

3. The Arrows of Time: Multidisciplinary Inquiries into Temporal Directionality

The concept of "arrows of time" is explored across multiple disciplines, from physics to psychology. In physics, the no-boundary quantum state theory suggests that fluctuations grow in the direction of expansion, defining a fluctuation arrow of time that aligns with other arrows like thermodynamic and electromagnetic (Hartle and Hertog, 2011). The emergence of time's arrows and special science laws from microphysics is discussed, proposing that thermodynamics relates to fundamental dynamical laws (Loewer, 2012). Some argue that cosmology generates thermodynamics, linking the universe's

expansion to the second law of thermodynamics (Gal-Or, 1972). In developmental psychology, even young children (3.5-4.5 years) demonstrate sensitivity to the unidirectional nature of certain transformations, recognizing anomalies in backward versions of gravity and separation events (Friedman, 2003). These diverse perspectives highlight the multifaceted nature of time's directionality across scientific domains.

"Arrow of time" is a fundamental yet perplexing aspect of our universe, describing the unidirectional flow from past to future (Wasserman, 2022). This phenomenon is closely linked to the Second Law of Thermodynamics and shapes human experiences and histories (Wasserman, 2022). Recent research suggests that the default mode network (DMN) plays a crucial role in orchestrating the hierarchy of brain dynamics and the arrow of time in cognition (Deco et al., 2022). Some researchers propose that the arrow of time is intrinsic to all systems, no matter how small, and fundamental in nature (Buchholz and Fredenhagen, 2023). However, other studies argue that time-reversal symmetry is maintained in standard dissipative equations of motion for both classical and quantum systems, suggesting that thermalization occurs both into the future and the past (Guff et al., 2023). These contrasting views highlight the ongoing debate surrounding the nature and origin of the arrow of time.

4. Definition of Three Arrows of Time

4.1. Thermodynamic Arrow of Time

The thermodynamic arrow of time is characterized by the unidirectional progression of entropy increase, as prescribed by the Second Law of Thermodynamics. Within any closed system, physical processes tend intrinsically toward states of higher entropy—that is, from greater order to greater disorder. This entropic gradient furnishes a macroscopic, empirically discernible orientation to temporal succession, thereby endowing time with an irreversible structure at the phenomenological level. (Price, 1996)

4.2. Psychological Arrow of Time

The psychological arrow of time denotes the asymmetry inherent in human temporal experience, wherein the past is retained in memory while the future remains epistemically inaccessible. This directional structure of consciousness coheres with our intuitive grasp of causality and underlies the sequential unfolding of subjective awareness. It thus manifests as a phenomenological corollary to the physical arrows of time, anchoring temporality within the lived experience. (Carroll, 2010)

4.3. Cosmological Arrow of Time

The cosmological arrow of time, which points in the direction of cosmic expansion, is a fundamental concept in cosmology. It is proposed that it causes the arrow of time associated with retarded radiation, supporting the hypothesis that stars radiate light due to universal expansion (Yurova et.al., 2022). In bouncing cosmology models, the cosmological arrow reverses at the bounce, though other arrows like perturbation growth can still differentiate between expanding and contracting phases (Cesare, 2024).

5. The Influence of Three Arrows of Time on Colour Perception

In this section, the author integrates the conceptual framework of temporal arrows with the mechanisms underlying colour perception.

The thermodynamic, psychological, and cosmological arrows are particularly relevant for understanding the temporal underpinnings of human sensory experience. Though colour perception is typically treated as an immediate, spatial phenomenon governed by optical and neurological factors, it is in fact subtly conditioned by these broader temporal arrows. Each introduces a unique orientation in time, shaping the contexts and mechanisms through which colour is experienced, remembered, and conceptualized.

5.1. Thermodynamic Arrow (The Progression Toward Disorder)

The thermodynamic arrow stems from the second law of thermodynamics, which asserts that entropy, or disorder, tends to increase in isolated systems. This principle gives rise to the irreversible flow of time and has practical consequences for both natural and artificial systems that produce or mediate colour.

Impact on Colour Perception:

- Pigment Degradation and Material Change: Over time, chemical and physical processes driven by entropy alter the properties of pigments and dyes. Oxidation, photodegradation, and environmental exposure degrade chromatic surfaces, resulting in fading, yellowing, or discoloration. This natural transformation causes colour to function as a marker of temporal passage in physical objects.

- Entropy in Optical Devices: Lenses, screens, and imaging sensors are likewise subject to wear, optical distortion, and material fatigue, which influence how colours are recorded and displayed. These changes accumulate in a one-directional manner, demanding recalibration in high-precision instruments.

- Temporal Colour Stability: In visual systems, the brain's ability to maintain perceptual constancy in the face of material degradation is an adaptive response to the entropic dynamics of the environment. Our perceptual apparatus interprets chromatic information within this thermodynamically evolving context.

- Scientific and Cultural Implications: In disciplines such as conservation science and archaeology, understanding how colours age under entropic influence is critical for reconstructing original appearances. Entropy thus informs both empirical study and cultural memory.

5.2. Psychological Arrow (Subjective Temporal Flow)

The psychological arrow represents the asymmetry of conscious experience—namely, that we remember the past and anticipate the future, but do not reverse this order. This forward flow of psychological time directly influences how we interpret visual information, including colour.

Impact on Colour Perception:

- Sequential Processing and Chromatic Memory: The brain processes visual stimuli as temporally continuous. Colour adaptation, aftereffects, and contrast illusions depend on the temporal sequencing of stimuli and on internal predictions based on past experience. What we see is filtered through what we have just seen.

• Time-Linked Emotional Colour Coding: Human cultures often associate specific colour palettes with temporal moods or times of day. Warm hues tend to evoke late-day or autumnal settings, whereas cooler tones may evoke early morning or springtime. These chronotopic associations embed colour within a temporal and emotional lexicon.

• Memory and Reconstruction of Colour: Human memory for colour is imperfect and temporally dynamic. Over time, memories of colour tend to shift or fade, and reconstruction is often influenced by emotional tone, contextual cues, and current perceptual states—making colour memory a temporally modulated process.

• Predictive Mechanisms in Colour Perception: According to predictive processing theories in neuroscience, perception is not purely reactive but anticipatory. The brain uses prior temporal patterns to forecast chromatic input, meaning that perception itself is an active process shaped by time-bound expectation.

5.3. Cosmological Arrow (Expansion of the Universe)

The cosmological arrow reflects the temporal direction implied by the ongoing expansion of the universe since the Big Bang. This arrow establishes a universal chronology, upon which the thermodynamic and causal structures of the cosmos are built. Although distant from immediate sensory experience, it informs several dimensions of how colour is used and interpreted in scientific and aesthetic contexts.

Impact on Colour Perception:

• Redshift as a Temporal Indicator: Due to cosmic expansion, light emitted from distant galaxies is stretched to longer wavelengths, producing a redshift. While this shift lies beyond unaided human perception, it is fundamental to astronomy and cosmology, serving as a temporal indicator of the age and distance of celestial bodies.

• Chronological Representation in Scientific Imagery: In astrophysics, colour-coded visualizations often translate non-visible wavelengths into the visible spectrum to render temporal or spectral information. Thus, colour becomes a tool for encoding time, allowing observers to grasp the temporal layering of the cosmos visually.

• Cultural and Artistic Engagements: Artistic depictions of the cosmos often rely on colour gradients to represent temporal progression—from the cool blues of an early universe to the warm reds of galactic maturity. These chromatic conventions mirror our understanding of cosmological time and embed it in visual culture.

• Photons as Time Capsules: The light we observe from distant stars represents emissions from earlier epochs, often millions or billions of years in the past. Each photon carries with it a temporal imprint, and so cosmic colour perception becomes an act of looking into the past, structured by the universe's expansion.

Conclusions

The present review has sought to elucidate the multifaceted influence of the arrows of time—thermodynamic, psychological, and cosmological—on the complex phenomenon of colour

perception. By integrating insights from physics, neuroscience, psychology, and cosmology, this synthesis underscores that colour perception is not merely a spatial or instantaneous sensory event but is deeply embedded within the irreversible and directional fabric of temporal experience.

The thermodynamic arrow, grounded in the inexorable increase of entropy, fundamentally shapes the material substrates of colour through pigment degradation and device aging, highlighting colour as a dynamic marker of temporal progression in physical systems. Concurrently, the psychological arrow, manifesting in human conscious experience and memory, reveals how colour perception is temporally sequenced, influenced by past stimuli, and shaped by anticipatory cognitive processes that rely on temporal continuity. This forward-moving subjective time infuses colour with mnemonic and emotional dimensions, enriching its perceptual and cultural significance. Finally, the cosmological arrow situates colour perception within the grand temporal narrative of the universe's expansion, exemplified by cosmic redshift and the encoding of temporal information in astrophysical imagery. Here, colour becomes a vehicle for accessing the distant past, linking human perception to the universal timescale.

Together, these temporal arrows demonstrate that colour perception transcends isolated physiological mechanisms, operating instead as a temporally layered construct that reflects both physical irreversibility and the human experience of time. This perspective invites future interdisciplinary research to further dissect the interplay between time's directionality and sensory phenomena, advancing our understanding of how fundamental physical laws and cognitive architectures converge to shape perceptual reality.

In sum, recognising the role of time arrows in colour perception not only enriches the theoretical framework of sensory science but also reinforces the enduring principle that time's unidirectional flow underpins the very fabric of how we perceive, remember, and interpret colour in the natural and cosmic worlds.

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The modulation of human aesthetic attraction by avian chromatic attributes

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Abstract

The interplay between avian coloration and human aesthetic attraction represents a complex interface between biology, perception, and cultural valuation. This review synthesizes current empirical findings on how specific chromatic attributes of birds modulate human visual preferences, integrating perspectives from avian biology, human visual perception, and aesthetic psychology. We examine the biological underpinnings of avian coloration, distinguishing pigmentary and structural mechanisms, and their evolutionary and environmental determinants. Subsequently, we analyze how these color traits—particularly saturation, hue, and contrast—influence human aesthetic judgments, drawing on large-scale citizen science data and experimental aesthetics research. Our review highlights consistent preferences for vivid colors such as blues and reds, and features like iridescence and pattern complexity, which align with broader principles of human visual aesthetics including symmetry and contrast. Furthermore, we discuss the limitations imposed by differences in avian and human visual systems, including the inability of humans to perceive ultraviolet wavelengths, and how these differences affect the interpretation of avian color signals. Finally, we consider the ecological and conservation implications of human aesthetic biases toward certain bird species, emphasizing the role of aesthetic attraction in shaping public engagement and biodiversity preservation efforts. This comprehensive review underscores the multifaceted nature of human-avian aesthetic interactions and identifies avenues for future interdisciplinary research.

Keywords: avian coloration, human aesthetic preference, structural color, pigmentary color, visual perception.

Introduction

The aesthetic appreciation of birds has been a subject of human fascination for centuries, deeply embedded in cultural, artistic, and natural history traditions. Historically, birds have captivated human observers not only through their melodic vocalizations but more prominently via their vivid and diverse coloration, which has inspired art, symbolism, and scientific inquiry alike. Despite the longstanding human interest in avian beauty, a comprehensive understanding of how specific chromatic attributes modulate human aesthetic attraction remains elusive. This gap is particularly significant in the context of advancing interdisciplinary research that bridges visual sciences, ornithology, and human perceptual psychology.

Bird coloration represents a remarkable evolutionary outcome of both pigmentary and structural mechanisms, producing an array of hues and patterns that vary widely among species. These chromatic features serve crucial biological functions—ranging from sexual signaling and species recognition to camouflage and thermoregulation—yet they also appear to exert a profound influence on human observers' aesthetic preferences. Early studies have recognized that humans tend to favor birds exhibiting vivid colors such as blues, reds, and greens, alongside morphological traits like crests and tails, which together contribute to perceptions of beauty and attractiveness. This predilection resonates with broader principles of human visual aesthetics, including preferences for color saturation, contrast, and symmetry, which have been well documented across cultures and artistic domains.

Modern empirical approaches now leverage large-scale datasets, including citizen science initiatives assessing aesthetic ratings of thousands of bird species globally, to quantify and model the traits driving human attraction. These efforts underscore the influence of not only chromatic characteristics but also familiarity and ecological context, suggesting that aesthetic preferences are shaped by a complex interplay of perceptual, cognitive, and cultural factors. Additionally, the disparity between human trichromatic vision and the tetrachromatic visual systems of birds, which include ultraviolet sensitivity, presents both challenges and opportunities for interpreting human assessments of avian coloration.

In light of growing anthropogenic pressures that threaten biodiversity and the integrity of natural visual environments, understanding the factors that govern human aesthetic responses to bird coloration gains practical importance. Such knowledge can inform conservation strategies, environmental education, and the promotion of cultural ecosystem services tied to biodiversity appreciation. This review synthesizes existing research on the biological basis of avian coloration, human perceptual mechanisms, and the resulting aesthetic attraction, aiming to clarify the role of chromatic attributes in shaping the enduring human fascination with birds.

Methods

A narrative literature review was conducted to clarify the current scientific understanding of human aesthetic attraction to birds. The search, conducted up to August 06, 2025, utilized the PubMed, Web of Science, Scopus, Google Scholar and CrossRef, focusing on English-language peer-reviewed articles published until 06th August 2025. The search strategy employed Boolean operators with the following algorithms: (“avian coloration”) , (“human aesthetics”), (“avian coloration” AND “human aesthetics”) , (“avian coloration” AND “human visual perception”), (“avian coloration” AND “biologic foundations”) , (“human aesthetics” AND “chromatic beauty”) , (“human aesthetics” AND “bird chromatic beauty” AND “modulation”) and (“human aesthetics” AND “chromatic beauty”). Exclusion criteria included case reports, letters to the editor, and conference abstracts. The review process proceeded in several stages. Initially, interdisciplinary evidence was gathered and categorized, incorporating both classical foundations and recent innovations. Outdated knowledge that have been superseded by more recent studies were excluded. Subsequently, data extraction was performed, followed by an interdisciplinary narrative synthesis of the findings."

Conceptualizing Human Aesthetic Attraction to Birds

Humans exhibit aesthetic preferences for certain bird characteristics. Smaller birds with vivid colors (especially blue and red) and and ornamental features, as well as species with broader ranges (Santangeli *et al.,* 2023). These preferences align with broader human visual aesthetic preferences in modern society (Santangeli et al., 2023). A large-scale citizen science project quantified the visual aesthetic attractiveness of over 11,000 bird species, providing a comprehensive dataset for further research (Haukka et al., 2023). Bird shape and overall lightness also significantly influence human preferences (Lišková and Frynta, 2013). Interestingly, species with broader ranges tend to be more aesthetically appealing, possibly due to increased familiarity (Santangeli *et al.,* 2023). However, the attraction to average or prototypical exemplars extends beyond faces to various stimuli, including birds, suggesting a more general cognitive mechanism rather than an evolved preference specific to mate selection (Halberstadt and Rhodes, 2000).

Research on bird attractiveness in urban landscapes found that built infrastructure and fragmentation reduce overall bird assemblage attractiveness, while diverse vegetation can support colorful species with varied calls (Suárez-Castro et al., 2024). Another study developed an attention-based model for

visual recognition tasks, incorporating human gaze data to improve attribute localization and classification of bird species (Bai et al., 2024).
Human aesthetic attraction to birds and related visual stimuli is explored. Fischer *et al.* (2025) found that ornithological research over six decades has been biased towards visually appealing and familiar bird species, potentially skewing conservation efforts and scientific knowledge. Mendelson *et al.* (2025) proposed a biological definition of beauty as the pleasure derived from fluent information processing, extending this concept to animal signals beyond sexual ornaments. They posit that beauty constitutes the experience of pleasure derived from efficient and fluent information processing, independent of any functional utility or consummatory reward associated with the stimulus. This conceptualization is elaborated through an analysis of three fundamental attributes of beauty—pleasure, interaction, and disinterestedness—alongside the psychological differentiation between 'wanting' and 'liking'. (Yuan *et al.* (2025) investigated the classification and aesthetic value of bird motifs in Chinese ceramic paintings, highlighting their cultural significance. The porcelain surface motifs in Chinese flower-and-bird paintings embody a profound cultural reverence for the intrinsic beauty of avian species. Birds are represented not merely as components of the natural environment but are also esteemed for their aesthetic qualities and emblematic significance. These studies collectively demonstrate the complex interplay between human perception, aesthetics, and scientific inquiry, with implications for both biological research and cultural expressions.

Chromatic Beauty in Human Aesthetics
Research in empirical aesthetics has explored human preferences for various visual and auditory attributes. Studies have found that aesthetic preferences are influenced by formal features like symmetry, complexity, proportion, contrast, and brightness across cultures (Che *et al.,* 2018). In the domain of color, individuals show preferences for certain hues, with blue being generally favored and yellow disliked (McManus *et al.,* 1981). These preferences may stem from basic perceptual and valuation processes shared among humans and other animals (Che *et al.,* 2018). Visual aesthetics research has employed various methodologies, including forced-choice tasks, subjective ratings, and production/adjustment techniques (Palmer *et al.,* 2013).

Research on chromatic attributes and aesthetic preference reveals complex relationships between visual features and human judgments of beauty. Studies have found that image statistics like fractal dimension and spectral slope can predict aesthetic preferences for natural scenes and artworks (Swartz *et al.,* 2023). However, the link between natural scene statistics and art preference is not straightforward (Maule *et al.,* 2021). Cross-cultural studies suggest some universal aesthetic preferences based on formal features like symmetry, complexity, and contrast (Che *et al.,* 2018).

The Biological Foundations of Avian Coloration
Avian coloration arises from both pigmentary and structural sources, with recent research shedding light on their biological foundations. Pigmentary colors are produced by molecules like carotenoids and psittacofulvins, while structural colors result from the interaction of light with nanoscale materials in feathers and skin (Price-Waldman and Stoddard, 2021). Vivid structural coloration constitutes a prominent and functionally significant aspect of avian phenotype, arising from an extensive array of integumentary photonic nanostructures within the skin and feathers. In contrast to pigment-based coloration—whose genetic underpinnings are increasingly well characterized—the developmental mechanisms governing structural coloration remain poorly understood. The development of structural colors involves intracellular self-assembly processes similar to those in soft colloidal systems (Saranathan and Finet, 2021). Pigment patterns in birds occur at both macro (across the body) and micro (within a feather) levels, controlled by melanocyte behavior and interactions with neighboring cells (Inaba and Chuong, 2020). Environmental factors like sex hormones can

further modulate these patterns, contributing to sexual dimorphism in plumage coloration (Inaba and Chuong, 2020).

Melanocytes produce eumelanin and pheomelanin, contributing to macro- and micro-level pigment patterns across the body and within feathers (Inaba and Chuong, 2020). Structural coloration, previously thought absent in Palaeognathae, has been discovered in cassowary feathers and extinct Lithornithidae, suggesting a potential intermediate between matte and iridescent plumage (Eliason and Clarke, 2020). Plumage colors in diverse bird families tend to cluster along lines in tetrachromatic color space, often containing complementary colors for enhanced contrast (Krishnan *et al.,* 2020). Anthropogenic pollution generally negatively impacts avian coloration, with carotenoid-based colors being most affected. However, no significant interaction between pollution types and color-producing mechanisms was found, and males did not show heightened sensitivity as expected (Janas *et al.,* 2024). These findings highlight the intricate nature of avian coloration and its susceptibility to environmental factors.

Feathers serve multiple functions throughout a bird's life, influencing their evolution and adaptation to diverse environments (Terrill & Shultz, 2022). Environmental exposure can alter plumage coloration post-moult, with UV/blue structural coloration changing differently in urban versus rural habitats. However, these changes may be below birds' perceptual thresholds (Surmacki et al., 2023).

In parrots, a single enzyme (ALDH3A2) regulates the balance of red and yellow psittacofulvin pigments, explaining the evolutionary flexibility of their plumage colors (Arbore *et al.,* 2024). Hyperspectral imaging has emerged as a powerful tool for studying animal coloration, allowing for detailed analysis of plumage colors and their perception by different visual systems (Hogan and Stoddard, 2024). The evolution of color vision predates the development of conspicuous coloration in plants and animals, with an explosion of color diversity occurring within the last 100 million years, including numerous origins of aposematic and sexually selected coloration (Wiens and Emberts, 2024). These findings contribute to our understanding of the physiological and biochemical bases of bird coloration.

Human Perception of Avian Coloration

Research on human visual perception of avian coloration reveals both limitations and surprising correlations. Birds possess sophisticated visual systems that enable complex color perception and cognition. Their tetrachromatic vision, based on four cone types and fine-tuned by carotenoids in oil droplets, allows for excellent color discrimination and constancy (Kelber, 2019). They possess UV-A sensitivity (Bennett and Théry, 2007), whereas humans are trichromatic. While human vision cannot detect ultraviolet wavelengths visible to many birds (Håstad and Ödeen, 2008), studies show that human assessments of plumage coloration can still provide meaningful data for comparative analyses (Seddon *et al*., 2010; Bergeron and Fuller, 2017). Human vision can detect much of the variation in avian coloration within the visible spectrum, although field guide representations may differ significantly from actual plumage reflectance (Bergeron and Fuller, 2017).

Human assessments of plumage color can provide meaningful estimates of sexual dichromatism for comparative analyses, particularly in violet-sensitive avian families (Seddon *et al.,* 2010). However, discrepancies exist between human and avian perception of sexual dichromatism, with some species appearing monochromatic to humans but dichromatic to birds (Seddon et al., 2010; Håstad and Ödeen, 2008).

The relationship between carotenoid pigments in both avian coloration and vision suggests a potential link between signal production and perception, but modeling indicates this connection may be subtle (Toomey and Ronald, 2021). While spectrophotometry and visual models can improve color measurements, human vision can still detect meaningful variation in avian coloration, particularly in species with violet-sensitive visual systems (Seddon *et al.,* 2010; Bergeron and Fuller, 2017). In human and avian color discrimination discrepancies exist in ranking plumage colors, emphasizing the importance of species-specific visual modeling in studying avian color signals (Håstad and Ödeen, 2008).

Exposure to urban environments can alter plumage coloration, with UV/blue chroma decreasing in urban areas but increasing in rural settings, though these changes may be below birds' perceptual thresholds (Surmacki *et al.,* 2023). Anthropogenic pollution generally has a detrimental impact on avian coloration, with carotenoid-based pigments being most affected. Contrary to expectations, no significant differences were found between males and females in sensitivity to pollution effects on coloration (Janas *et al.,* 2024).

Aesthetic Allure: Human Fascination with Bird Coloration

Recent studies have explored human aesthetic preferences for birds, revealing key factors that influence our attraction. Smaller birds with vivid colors, particularly blue and green, and distinctive features like long crests or tails are generally preferred (Santangeli et al., 2023; Lišková & Frynta, 2013; Lišková et al., 2015). Bird shape plays a significant role in determining attractiveness, with overall lightness and pattern also being important factors (Lišková & Frynta, 2013; Lišková et al., 2015). Interestingly, species with broader ranges tend to be more aesthetically appealing, possibly due to familiarity (Santangeli et al., 2023). These preferences align with broader human visual aesthetic preferences in modern society (Santangeli et al., 2023). Understanding these factors can inform conservation efforts and education campaigns by leveraging the cultural ecosystem service potential of birds (Santangeli et al., 2023). Large-scale datasets, such as the iratebirds Citizen Science Project, now provide comprehensive measures of birds' visual aesthetic attractiveness to humans across species (Haukka et al., 2023).

In the Anthropocene, where human influence shapes ecosystems globally, understanding how we relate to other species is crucial. Aesthetic appreciation is a key factor in this relationship, especially in the case of birds, which are widespread and emotionally resonant to humans. Their beauty draws strong public interest and fuels ecotourism, yet we still lack a comprehensive understanding of what makes certain species more visually appealing. To derive final measures of visual aesthetic attractiveness, rating scores were modeled across a comprehensive dataset comprising 11,319 bird species and subspecies. Over 400,000 individual ratings were contributed by respondents from diverse backgrounds. This represents the first systematic effort to quantify the global visual aesthetic appeal of birds from a human perspective (Haukka *et al.,* 2023). Using this global citizen-science dataset encompassing nearly all bird species (Haukka et al., 2023), it has been shown that human aesthetic attraction is linked to specific traits: small body size, vivid colors like blue and red (in contrast to dull tones), and pronounced features such as long crests or tails. (Santangeli *et al.,* 2023; Lišková and Frynta, 2013; Lišková *et al.,* 2015). Additionally, species with large geographic ranges tend to be rated as more attractive, likely due to greater familiarity (Santangeli et al., 2023). These preferences align with broader visual aesthetics in contemporary human society. Identifying the visual cues that drive our attraction to birds is essential for advancing conservation outreach, education, and the cultural valuation of biodiversity.

The allure of iridescent coloration in birds has sparked interdisciplinary studies exploring its optics, evolution, and functions (Meadows *et al.,* 2009). Importantly, the perceived beauty of bird species influences their representation in captive populations, with zoos preferentially keeping larger, more colorful, and long-tailed parrots (Frynta *et al.,* 2010). This aesthetic preference may have implications

for conservation efforts, as it affects which species receive more attention in captive breeding programs. Understanding human attraction to bird aesthetics could inform conservation marketing strategies and leverage the cultural ecosystem services provided by birds (Santangeli *et al.,* 2023).
Extra-pair paternity influences sexual dichromatism, with high-EPP species exhibiting more conspicuous males and cryptic females (Valcu *et al*., 2025). Red carotenoid coloration, often considered an honest signal of quality, involves complex metabolic pathways and cellular processes, though the exact mechanisms linking coloration to individual fitness remain unclear (Koch *et al.,* 2025). Urban-adapted bird species tend to display more elaborate colors, particularly blue, dark grey, and black, while brown and yellow are less common in urban environments (Ibáñez-Álamo *et al.,* 2025). Feathers, responsible for various functions including coloration, exhibit a remarkable hierarchical structure from nano to macro scales. This multi-functional design, achieved through subtle architectural differences rather than chemical composition, enables diverse properties across bird species and inspires biomimetic applications (Hendrickx-Rodriguez and Lentink, 2025). These studies collectively highlight the complexity and significance of bird coloration in various ecological contexts.
The allure of bird coloration extends beyond scientific interest, with structural colors being used in art throughout history (Finet, 2023). However, this human fascination with colorful birds has a dark side, as it drives wildlife trade and threatens biodiversity (Senior *et al*., 2022). Colorful passerines are particularly targeted, with hotspots of color diversity concentrated in the tropics, potentially eroding nature's aesthetic value (Senior *et al.,* 2022). The tropical regions constitute a pronounced global epicenter for avian coloration, hosting 91% of the most chromatically diverse and 65% of the most uniquely colored passerines. Analysis shows that the pet trade—impacting about 30% of passerine species—is phylogenetically biased, targeting closely related, vividly colored species. We identify 478 additional species at risk, potentially increasing trade-affected species by 34% to 1,886. Extinction risk models predict regional losses in color diversity and uniqueness, which may substantially diminish the aesthetic complexity of avian assemblages and accelerate the homogenization of the natural visual environment (Senior *et al.,* 2022).

Conclusions

In conclusion, human aesthetic attraction to avian coloration reflects a complex interplay of biological and cultural factors. Empirical evidence supports traditional aesthetic principles—such as harmony, vividness, and prototypicality—showing a consistent preference for small birds with bright colors (e.g., blues and reds) and distinctive features like crests and long tails. These preferences align with innate perceptual biases and learned familiarity, especially for widely distributed species.

Biologically, avian coloration results from intricate pigmentary and structural mechanisms, producing vivid hues perceptible despite differences between human and avian visual systems. This perceptual overlap affirms the relevance of classical color attributes—hue, saturation, and contrast—in human aesthetic evaluations.

The appeal of colorful birds extends beyond science, influencing conservation efforts, artistic expression, and ecotourism. However, it also drives demand that threatens species in biodiversity-rich regions. Balancing aesthetic appreciation with ethical stewardship requires integrative approaches grounded in both tradition and interdisciplinary research, bridging evolutionary biology, perceptual psychology, and cultural heritage.

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Color and Psychology

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Color Sensitivity: How Hue and Saturation Influence Food Selection in Nickel Allergy

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Abstract

Nickel allergy is the most common form of allergic contact dermatitis (ACD) worldwide, with notable gender differences in prevalence. While its dermatological effects are well-established, the broader neuropsychological and perceptual implications remain largely unexplored. This study examines the potential influence of nickel hypersensitivity on visual food perception, particularly focusing on how immune sensitization may alter sensory processing and emotional responses to food-related visual stimuli. A cross-sectional study was conducted involving participants with and without confirmed nickel allergy. All participants completed a detailed questionnaire assessing concerns related to food color, anxiety-related behaviors, vividness of mental imagery, and risk perception. Responses were rated using a Likert scale across various color categories. Statistical analyses included t-tests, chi-square tests, Pearson correlations, and multiple regression models controlling for demographic variables. Participants with nickel allergy exhibited heightened concern for specific food colors and demonstrated more vivid mental imagery and greater avoidance behaviors based solely on visual appearance. These perceptual differences remained significant even after adjusting for demographic factors. Nickel hypersensitivity may influence food perception through enhanced sensory vigilance, suggesting that allergic contact dermatitis can extend beyond cutaneous symptoms to affect cognitive and perceptual domains. These findings have potential implications for dietary guidance, food presentation strategies, and a deeper understanding of the psychosocial burden associated with allergic conditions.

Keywords: Nickel allergy, Color perception, Food psychology, Sensory vigilance, Cross-modal perception.

Introduction

Nickel allergy constitutes the most prevalent form of allergic contact dermatitis (ACD) worldwide, representing a significant public health concern with substantial socioeconomic implications. Current epidemiological data indicate that nickel sensitization affects approximately 8.6% of the general European population, with marked gender disparities showing prevalence rates of up to 17% in women and 3% in men (Thyssen et al., 2007; Ahlström et al., 2019). North American surveillance data corroborate these findings, with retrospective analyses revealing an average nickel sensitivity frequency of 17.5% among dermatitis patients between 1994-2014 (Warshaw et al., 2019). The pathophysiology of nickel allergy involves a complex type IV delayed-type hypersensitivity reaction mediated by hapten-specific T-lymphocytes (Schmidt et al., 2010). Upon initial sensitization, nickel ions (Ni^{2+}) form hapten-protein conjugates with skin proteins, particularly through cysteine and histidine residues, triggering the activation of Langerhans cells and dendritic cells as antigen-presenting cells (APCs) and subsequent T-helper 1 (Th1) and T-helper 17 (Th17) cell-mediated inflammatory cascades (Martin et al., 2011). This immunological memory results in rapid inflammatory responses upon re-exposure, manifesting as erythema, vesiculation, scaling, and intense pruritus typically occurring 12-72 hours post-contact (Menné & Maibach, 1989; Johansen et al., 2011).

Color represents a fundamental dimension of visual perception that profoundly influences human cognition, emotion, and behavior through both innate and learned associations (Bortolotti et al., 2022; Elliot & Maier, 2014). In the context of food perception, color serves as the primary product-intrinsic sensory cue in establishing expectations regarding taste, flavor, freshness, and safety (Bortolotti et al., 2025a; Spence et al., 2010). Food colors processed through the ventral visual stream, involving interactions between the visual cortex (areas V1-V4), fusiform color area, and limbic structures including the amygdala and orbitofrontal cortex (Hurlbert & Owen, 2015). The neurobiological substrates of color processing involve complex trichromatic mechanisms mediated by long (L), medium (M), and short (S) wavelength-sensitive cone photoreceptors, with subsequent processing through opponent color channels (red-green, blue-yellow, and luminance) (Hunt et al., 2009).These neural pathways contribute to the emotional valence and cognitive appraisal of visual stimuli, with specific colors eliciting predictable psychological and physiological responses across cultures (Palmer &Schloss, 2011).
Research demonstrates that warm colors (red, orange, yellow) typically stimulate appetite and convey ripeness or energy density, while cool colors (blue, green) may suggest freshness, naturalness, or in some cases, spoilage (Spence et al., 2010; Piqueras-Fiszman & Spence, 2014). These associations are mediated by both evolutionary adaptations and cultural learning, with implications for food choice behavior and dietary preferences (Roullet & Droulers, 2005). Despite the theoretical plausibility of allergy-related perceptual alterations, empirical research examining the intersection of allergic contact dermatitis and sensory perception remains limited. This study addresses this knowledge gap by investigating how individuals with patch-test confirmed nickel allergy perceive food colors compared to non-allergic controls, utilizing a comprehensive battery of perceptual, cognitive, and behavioral measures. Based on the theoretical framework of enhanced sensory vigilance and cross-modal plasticity in allergic conditions, we formulated the following a priori hypotheses:

H1: Individuals with nickel allergy would demonstrate significantly elevated concern levels for food colors, particularly those associated with warm spectrum colors or foods with potential nickel content.

H2: Allergic participants would exhibit enhanced mental imagery vividness and emotional reactivity to food-related visual stimuli compared to controls.

H3: Color-based food avoidance behaviors would be more prevalent in the allergic group, independent of actual nickel content, reflecting generalized hypervigilance mechanisms.

H4: These perceptual differences would correlate with anxiety levels and risk perception measures within the allergic group, supporting a unified vigilance framework.

Methods
Participants were recruited through a multi-channel approach including online platforms, dermatology clinic referrals, and snowball sampling within university networks. The final sample consisted of 40 participants stratified into two groups based on their response to the diagnostic question: *"Hai mai ricevuto diagnosi di allergia o sensibilità al nichel tramite 'Patch Test'?"(*Have you ever received a diagnosis of nickel allergy or sensitivity through patch testing?). Participants responding affirmatively with documented patch test results (n=13) were classified as nickel-allergic, while those responding negatively (n=27) served as controls.

Color-Based Concern Assessment: Participants rated their concern (as allergy-related apprehension) toward foods of ten colors using a 5-point Likert scale. Colors were presented in random order.

Color-Nickel Association: Participants selected the color they most associated with high-nickel foods and rated agreement with the idea that food color indicates nickel content.

Food-Related Anxiety and Avoidance: Assessed frequency of anxiety when choosing foods based on appearance and whether participants had ever avoided food solely due to its color, despite knowing it was low in nickel.

Vividness of Visual Imagery Food Version (VVIQ-F): A 20-item questionnaire measured vividness of mental imagery across four domains (visual, olfactory, gustatory, multisensory) using a 5-point scale from the other similar scale like (Bortolotti et al., 2025b; Croijmans & Wang, 2022).

Nickel Risk Assessment Protocol
Participants viewed six standardized food images (three high-nickel, three low-nickel) (Figure. 1)

Figure 1.
High-nickel foods: Dark chocolate (>200 µg/100g), Lentils (>100 µg/100g), Green peas (>50 µg/100g). Low-nickel foods:White rice (<10 µg/100g), Potatoes (<10 µg/100g), Carrots (<15 µg/100g)

Perceived nickel content, Willingness to consume Trust in safety based on color (All on 7-point Likert scales)

Food Attitudes and Behavior Scale: A 6-item scale measured attitudes and behaviors related to: Food-related anxiety, Avoidance of unfamiliar foods, Perceived dietary control, Disgust toward unusual colors, Social/wellness limitations, Difficulty maintaining restrictive diets

Results
The final sample comprised 40 participants: 13 with patch-test confirmed nickel allergy, and 27 controls without nickel allergy. The two groups were comparable in terms of age, gender, and educational attainment, minimizing the risk of demographic confounding.
A clear pattern emerged showing heightened color-related concern among nickel-allergic participants. Subjects in the allergy group reported significantly higher concern scores for foods in warm color spectra specifically red, brown, and orange. For instance, the mean concern for red-colored foods was 2.92 in the allergic group versus 1.85 in controls ($p<0.001$, Cohen's $d=1.06$); brown scored 2.38 versus 1.44 ($p<0.01$, $d=0.99$); and orange 2.15 versus 1.33 ($p<0.05$, $d=0.93$). These differences were robust

and persisted after adjustment for demographic variables, while concern levels for "safe" colors (green, white, gray) showed no significant between-group differences (Figure. 2).

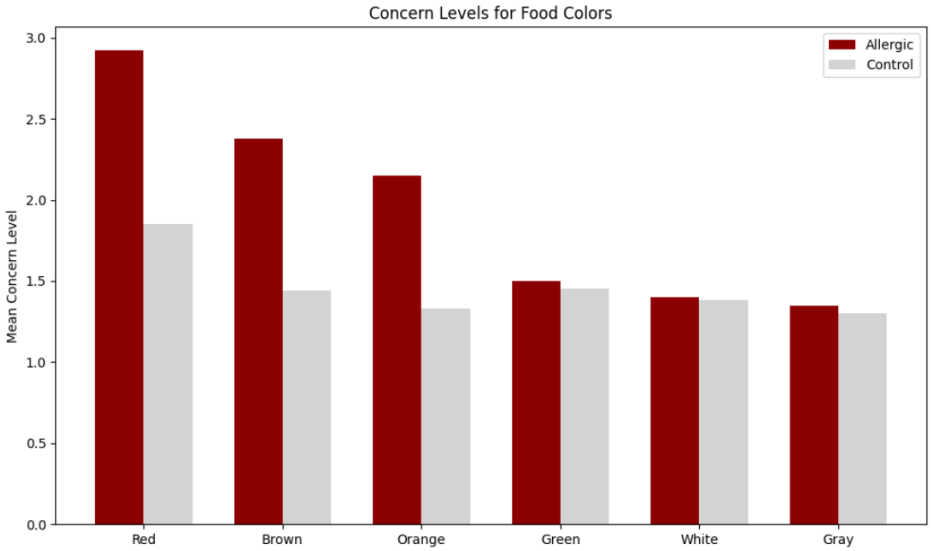

***Figure 2**: Bar chart presenting mean concern levels (1–5 scale) for all food color categories, comparing nickel-allergic participants (dark bars) to controls (light bars).*

Food-related anxiety and avoidance were also considerably more prevalent among allergic individuals. More than 84% of allergic participants frequently or very frequently avoided foods based solely on color, compared to less than 15% of controls. Similarly, 69% of allergic participants reported often or very often feeling anxious when selecting foods based on appearance, in stark contrast to 15% in the control group (Figure. 3).

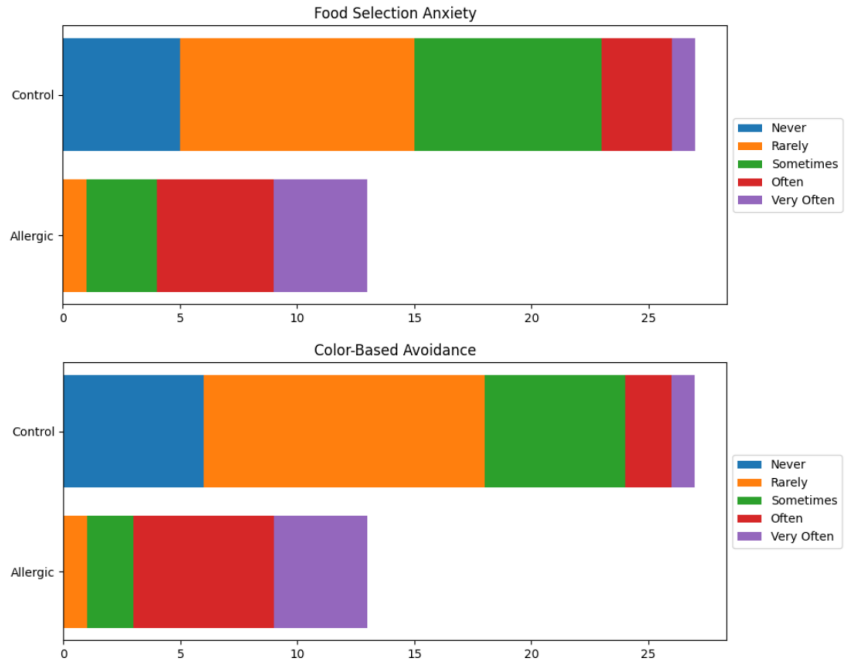

***Figure 3**: Stacked horizontal bar chart illustrating the distributions of food selection anxiety and color-based avoidance frequency in both groups. Different shades represent levels from "never" to "very often."*

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Mental imagery vividness for food-related scenarios was consistently higher among allergic participants, with moderate to large effect sizes. For example, vividness when visualizing chocolate, pizza, or fresh fruit was significantly greater in the allergy group (d range: 0.63–0.87), implying stronger and more emotionally charged food-related mental images (Figure. 4).

Figure 4*: Radar (spider) chart comparing mean scores for imagery vividness across six food scenarios, with separate lines for allergic and control participants.*

Risk perception and trust in food safety information were also significantly impacted by allergy status. The allergic group expressed markedly higher general concern about food safety (mean=5.23 vs. 3.87, $p<0.001$, $d=1.15$) and perceived risk of contamination, coupled with lower trust in both food safety labeling and information (4.15 vs. 5.41, $p<0.01$, $d=-1.01$).

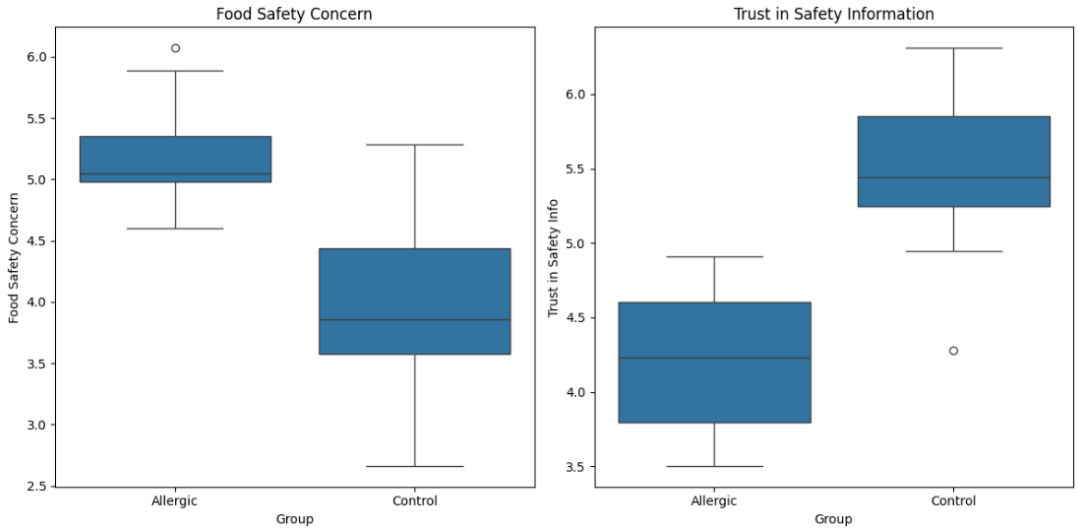

Figure 5*: Box plots showing distributions of general food safety concerns (left) and trust in safety information (right) for both groups. The allergic group consistently displays wider dispersion and less trust.*

Within the allergic group, strong positive correlations were found among color concern, food selection anxiety, and avoidance behavior (r=0.54–0.74). Trust in external safety information was inversely correlated with these vigilance-related concerns (r=–0.67), indicating that low confidence in information increases reliance on subjective visual cues (Figure. 6).

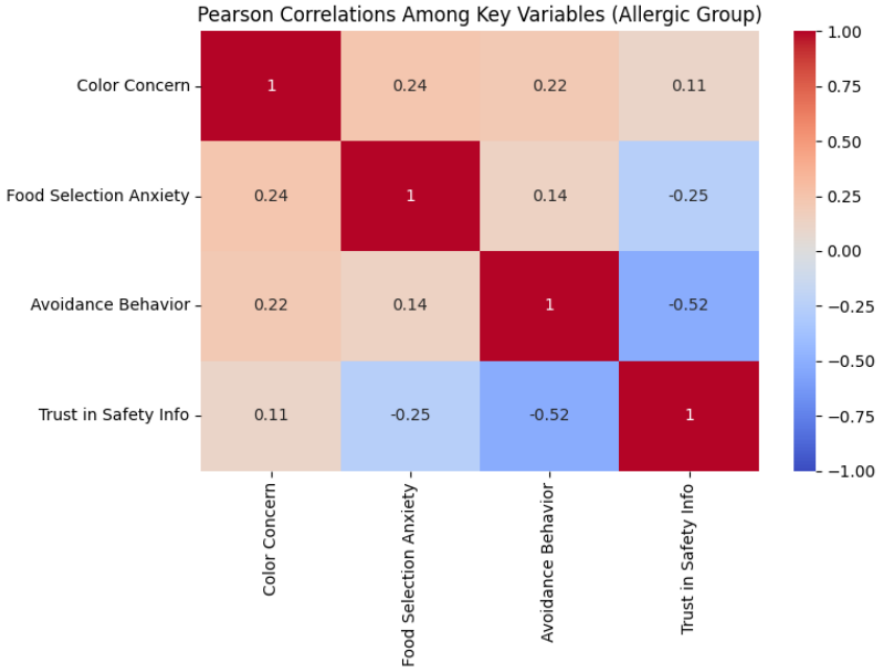

***Figure 6**: Heatmap displaying Pearson correlation coefficients among key variables in the allergic group. Strong associations are highlighted.*

Regarding specific foods, allergic participants discriminated accurately between high- and low-nickel foods but displayed overgeneralized vigilance for colors associated with higher nickel content. For low-nickel foods (such as rice, potatoes, carrots), there was no substantial difference between groups.

Discussion

The present study provides novel evidence that individuals with patch-test confirmed nickel allergy exhibit distinct alterations in visual food perception, particularly in relation to color. The findings support the hypothesis that immune sensitization may extend beyond dermatological manifestations to influence cognitive and perceptual domains. Specifically, allergic participants demonstrated significantly heightened concern for warm-colored foods (red, brown, orange), which are often associated with high-nickel content or perceived risk. This aligns with prior research on sensory vigilance and threat detection in allergic individuals, suggesting a generalized hypervigilance mechanism that may be visually mediated. Moreover, the elevated vividness of food-related mental imagery among allergic participants indicates a possible amplification of internal sensory representations, potentially contributing to stronger emotional responses and avoidance behaviors. These results are consistent with theories of cross-modal plasticity, where chronic immune activation may sensitize neural circuits involved in sensory integration and emotional regulation. The observed mistrust in food safety information further compounds this effect, leading to reliance on visual heuristics (e.g., color) as proxies for safety, even in the absence of objective risk.

The strong correlations between color concern, anxiety, and avoidance behaviors within the allergic group underscore the interconnectedness of perceptual, emotional, and behavioral responses. These

findings suggest that nickel allergy may function as a multisensory condition, with implications for dietary behavior, quality of life, and psychological well-being.

Several limitations must be acknowledged. First, the sample size was relatively small (n=40), which may limit the generalizability of the findings. Although statistical power was sufficient to detect medium-to-large effects, replication in larger and more diverse populations is warranted. Second, the study relied on self-reported measures, which may be subject to recall bias or social desirability effects. While the use of validated scales mitigates this concern, future studies could incorporate objective behavioral or physiological measures (e.g., eye-tracking, skin conductance).

Third, the cross-sectional design precludes causal inference. It remains unclear whether heightened visual sensitivity is a consequence of chronic allergy or a predisposing trait. Longitudinal studies are needed to disentangle these temporal dynamics. Finally, the study focused exclusively on nickel allergy; whether similar perceptual alterations occur in other forms of allergic contact dermatitis remains an open question.

Conclusion

This study demonstrates for the first time that patch-test confirmed nickel allergy is associated with substantial alteration in color-mediated food perception. Nickel-allergic individuals exhibit pronounced concern toward foods with warm color tones (notably red, brown, orange), paralleled by heightened anxiety and frequent avoidance behavior exclusively based on visual attributes, independent of actual nickel content. Enhanced vividness of food imagery and pervasive mistrust in food safety labelling further amplify these effects, suggesting a mechanism of generalized sensory vigilance driven by both immunological and neuropsychological processes.

These findings extend the clinical understanding of nickel allergy beyond cutaneous symptoms, highlighting substantial cognitive and behavioral implications. The marked avoidance and heightened risk perception may lead to unnecessary dietary restrictions and diminished quality of life, warranting the inclusion of psychological assessment and targeted counselling in allergy management. Trust in food safety information emerges as a potential intervention point to reduce unnecessary avoidance and anxiety. This work characterizes nickel allergy as a multisensory and multidimensional condition. It illustrates the complex interplay between immune activation, visual sensory processing, and psychological coping. Future longitudinal and neurophysiological studies are encouraged to further elucidate mechanisms and inform comprehensive therapeutic strategies.

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The Influence of Waiting Area Color Design on Healthcare Workers' Stress Perception in Pediatric Clinics: A Pilot Study

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Abstract

The physical environment of healthcare facilities has a direct impact on the quality of healthcare services and the well-being of medical personnel. In pediatric clinics, environmental colors play a significant role in shaping the emotional perceptions and experiences of all users, especially emotionally sensitive child patients and healthcare staff working under high-pressure conditions. Previous studies on color psychology in pediatric settings have frequently advocated the use of bright colors in conjunction with environmental graphics, to foster a cheerful and welcoming atmosphere aimed at minimizing patient stress levels in waiting rooms and doctors' offices. While recommendations for color use in pediatric clinic environments have been proposed, however healthcare workers' perspectives on environmental conditions are often overlooked. A literature review reveals limited research on healthcare workers' perceptions of environmental color. This study, therefore, aims to fill that gap by exploring healthcare workers' perceptions of wall color schemes in pediatric clinic environments. In this study, 45 healthcare workers in Bangkok, Thailand (aged 24–50; mean age = 33.75; 80% female; average work experience = 8.28 years) evaluated nine realistic, computer-generated scenes of a pediatric clinic waiting area decorated with different triadic color schemes and saturation levels. Each participant assessed their emotional responses using two adjective pairs from Mehrabian and Russell's PAD emotional state model, as well as their perceived stress levels. The results showed that while warm color scenes (yellow and red) received higher scores on the arousal scale, they scored lower on pleasure and had higher stress ratings compared to cool color scenes (green and blue). Data analysis indicated a significant difference in stress levels between scenes with low saturation (M = 6.92, SD = 1.56) and those with high saturation (M = 3.12, SD = 1.75), t(179) = 23.37, $p<.001$. The scene with a low-saturation green color scheme received the highest pleasure score, while the high-saturation red color scheme received the lowest. In conclusion, this study extends existing knowledge in environmental psychology by examining the impact of waiting area color design in pediatric clinics from the perspective of healthcare workers. Future research should explore a wider variety of color schemes and environmental graphic options and include the perspectives of patients' relatives along with other emotional and behavioral states.

Keywords: Stress, Environmental Color, Wall Color Scheme, Pediatric Clinic, Healthcare Workers, Color Psychology, Waiting Area Design.

Introduction

Growing evidence over the past decade highlights the significant influence of the physical environment in healthcare settings on both the quality of care and the well-being of healthcare worker (Cetin *et al*., 2018). Inadequate environmental conditions-such as poor lighting, disruptive noise, or overcrowded spaces-have been shown to negatively impact concentration, mood, and work performance (Ulrich *et al*., 2008; Gray *et al*., 2012). In Thailand, this issue is particularly critical in public hospitals with limited resources, where such environmental stressors contribute to excessive workloads and mental health challenges among healthcare workers (Thongpraween & Inkarojrit, 2018). Pediatric clinics, which serve vulnerable patients, demand even greater attention to environmental design for both patients and staff (Jin *et al*., 2022). Among these design elements, wall

color schemes have been identified as a key factor influencing emotions, feelings of safety, or psychological pressure (Yamsai & Inkarojrit, 2018).

A Preliminary survey of pediatric clinics in Bangkok revealed that while bright colors and Nature-themed decorations may appeal to children, they can have adverse effects on staff, such as visual fatigue and accumulated stress. Moreover, anxious child patients often increase the emotional burden on staff, potentially leading to burnout if not addressed with appropriate support mechanisms (Toida & Morimura, 2022; Buckley *et al.,* 2022). The differential environmental perception between children and adults underscores the need for balanced design that addresses the needs of both groups (Singh et al., 2024; Cho, 2023). Selecting appropriate color tones such as blue and green can help promote well-being, reduce stress, and enhance staff performance (Ghamari & Amor, 2016). This research aims to explore how wall color schemes within pediatric clinics contribute to Healthcare Workers' psychological responses and overall well-being. Grounded in environmental psychology and evidence-based design, the research aims to inform the creation of emotionally supportive clinical environments that enhance staff performance and quality of care. The objective of the study are:

- To investigate the physical environmental factors of pediatric clinics, with a focus on the role of wall color schemes as elements that enhance the emotional and psychological well-being of healthcare workers.
- To assess the relationship between wall color schemes in pediatric clinic environments and their impact on healthcare workers' stress levels.
- To propose design guidelines for wall color schemes in pediatric clinics that help reduce stress among Healthcare Workers.

Literature Review

A review of relevant literature highlights the impact of environmental color on emotional states and stress, particularly in healthcare settings for vulnerable groups. Building on these insights, this study developed a conceptual framework (Fig. 1) based on the Mehrabian and Russell's (1974). S–O–R model, illustrating how wall color schemes in pediatric clinics influence healthcare workers' stress perception and emotional responses.

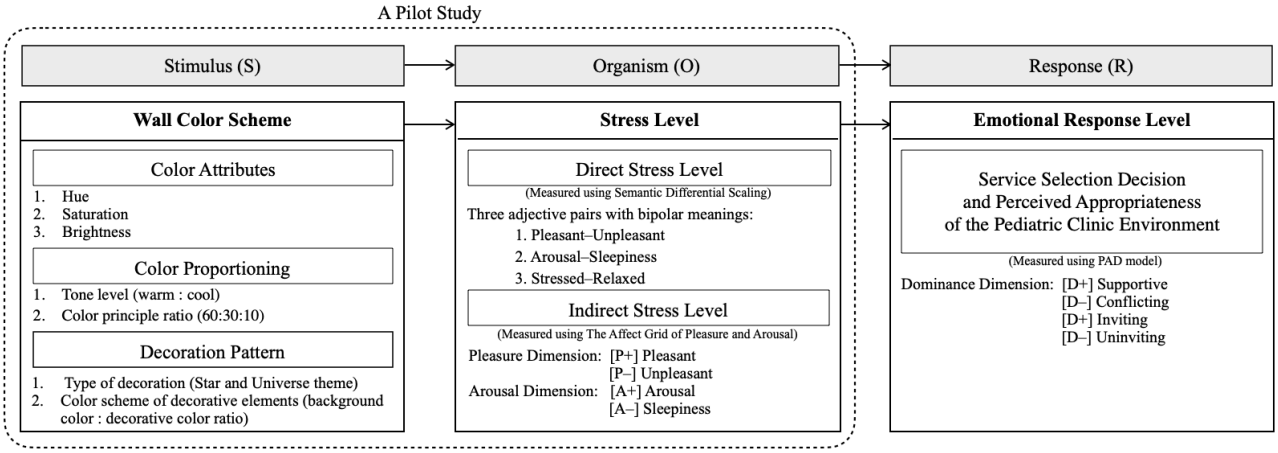

Fig. 1 - Conceptual Framework Based on the S-O-R Model from Mehrabian & Russell, 1974 (Source: Author)

In this study, the model begins with the Stimulus (S), which includes color attributes (hue, saturation, brightness), color proportioning (tone level, color ratio), and decoration patterns (e.g., star and universe theme). These visual elements influence the Organism (O) namely, healthcare personnel through the perception of stress levels, both direct (measured using Semantic Differential Scaling) and indirect (measured using the Affect Grid of Pleasure and Arousal). The Response (R) is reflected in the emotional outcome, specifically the service selection decision and the perceived

appropriateness of the pediatric clinic environment, will be addressed comprehensively in the subsequent dissertation research.

Research in environmental psychology and design has consistently affirmed that color is a key element that directly influences emotional perception, feelings, and stress levels of users, particularly in emotionally sensitive settings such as healthcare facilities and pediatric clinics (Cho, 2023; Singh *et al*., 2024). Natural tones such as green and light brown have been shown to reduce stress hormones and promote psychological recovery (Cho, 2023), while spatial color patterning can help minimize confusion and enhance concentration (Gray *et al*., 2012). Cool tones such as blue and green contribute to a calming effect and help reduce anxiety (Singh *et al*., 2024), whereas saturated and intense colors may increase stress, especially in pediatric clinics. Additionally, cultural context, age, and user experience also influence color perception (Park & Park, 2013). Therefore, environmental design should be flexible, aiming to foster positive emotions, reduce stress, and support the sustainable performance of medical personnel.

The review also shows that color characteristics in healthcare environments have a direct impact on users' stress levels, particularly among emotionally sensitive groups such as children, the elderly, and healthcare providers (Ulrich *et al*., 2008). Cool tones with low saturation, such as light blue and mint green, are effective in reducing anxiety and resistance behaviors, whereas warm and highly saturated colors may stimulate higher levels of stress. Assessing the psychological effects of color on stress involves tools such as the Osgood's Semantic Differential Rating and the Affect Grid Scale of Valence and Arousal (Russell *et al.*, 1989).

In summary, environmental color particularly hue, saturation, and brightness plays a critical role in shaping emotional states and stress levels, especially in healthcare settings for vulnerable groups. Cool, natural tones like green and blue are linked to calming effects, while warm, saturated colors may elevate arousal and fatigue. User factors such as age, culture, and experience also influence color perception. Building on this, the present study examines how wall color schemes in pediatric clinic waiting areas affect stress perception among healthcare workers. By applying environmental psychology and using tools like the Semantic Differential Scale and Affect Grid, the research aims to identify color attributes that support staff well-being and inform practical design strategies for more emotionally supportive healthcare environments.

Methodology

This study employed an experimental research design with quantitative data collection. The investigation focused on medical and support staff working in pediatric clinics within public and private hospitals in Bangkok. Participants were required to have no color blindness or communication impairments. A total of 45 participants were recruited using a non-probability sampling method.

A review of the literature indicates that color in children's waiting areas significantly affects psychological perception (Dalke *et al*., 2006; Singh *et al*., 2024). Observations of pediatric clinic environments also revealed that waiting areas often feature the highest color intensity compared to other zones. As such, this study focuses specifically on children's waiting areas, which have the potential to influence the emotional perception of healthcare workers. The simulated environments used in the study are illustrated in Fig. 2.

Fig. 2 - Floor plan showing a simulated pediatric clinic environment (left) and sectional view of the simulated environment (right) (Source: Author)

A field survey indicated that pediatric clinic interiors typically use multiple hues in varying proportions, influenced by elements such as doors, trims, and wall patterns. Drawing on the 60-30-10 design principle and Triadic Harmony from the NCS color wheel, each scheme was structured with 60% primary, 30% secondary, and 10% accent color to ensure visual balance. Wall designs were tailored to children's developmental stages, avoiding overly complex details. Accordingly, inspired by The Inspiring Universe – UNAWE Project (https://www.unawe.org), which has been shown to stimulate curiosity, a "star and universe" theme was applied. This concept also reflects Attention Restoration Theory (Kaplan, 1995), emphasizing that universe-inspired forms can promote relaxation and restore attention through soft fascination. Based on literature and field observations (Dalke *et al*., 2006; Jiang, 2020; Singh *et al*., 2024), the designs incorporated color zoning with this universe-inspired approach.

Independent Variable

This study selected the color properties for simulated wall schemes using the Natural Color System (NCS), which defines colors based on three perceptual attributes: hue, blackness, and chromaticness. Four primary hues most commonly found in pediatric clinic environments were chosen: yellow (-Y), red (-R), blue (-B), and green (-G)**.** Each hue was represented with varying levels of brightness and saturation to clearly distinguish between soft tones and strong tones**.** A neutral midtone, white (NCS S0300-N), was included as the control color, as illustrated in Fig. 3.

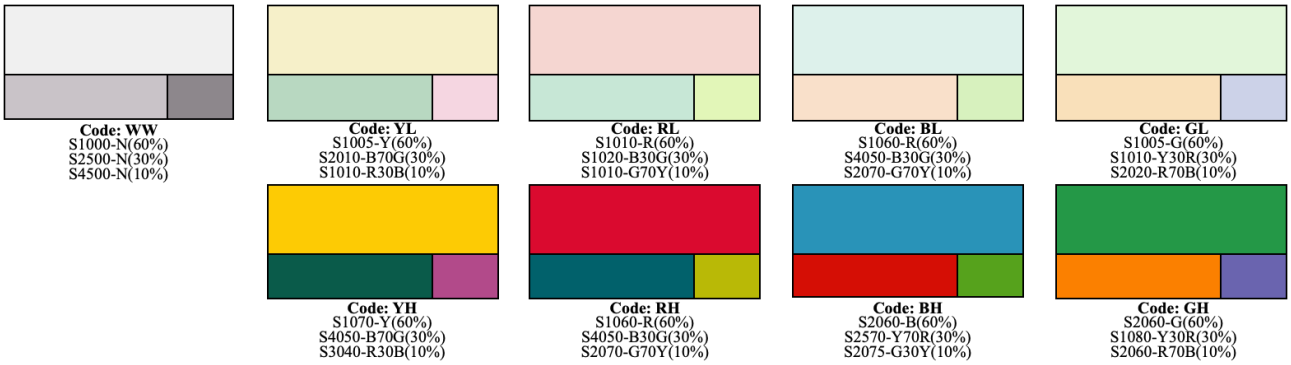

Fig. 3 - Definition of the Nine Wall Color Schemes (Source: Author)

Dependent Variable

Psychological stress levels were assessed using self-report evaluation tools, combining two measurement methods. This study employed both direct assessment through Semantic Differential Scalingand and indirect assessment using The Affect Grid of Pleasure and Arousal (Fig. 4). The evaluation was based on three pairs of bipolar adjectives: Pleasant–Unpleasant, Arousal–Sleepiness, and Stressed–Relaxed. These dimensions were aligned with Russell's affective model, allowing

researchers to capture emotional responses along axes such as stress–relaxation and excitement–depression, using a 9-point rating scale.

	1	2	3	4	5	6	7	8	9	
Unpleasant										Pleasant
Sleepiness										Arousal
Stress										Relaxed

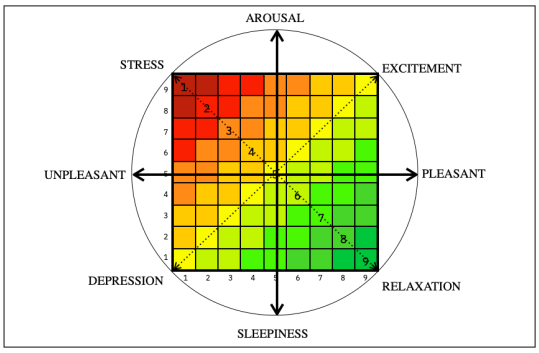

Fig. 4 - Direct stress level assessment using the Semantic Differential Scaling method. (Left) Indirect stress level assessment using the Affect Grid Scale. (Light) (Source: Author)

Data Collective and Analysis

Simulated Pediatric Clinic Environment Models: This study utilized visual simulation techniques to generate environmental models of pediatric clinic waiting areas. The simulations were created using using SketchUp Pro 2024 and D5 Render. The modeled space represented a typical pediatric waiting area (9.00 × 12.00 × 3.40 m), based on actual surveyed clinic spaces and proportionally adjusted for clarity and consistency for survey respondents. A total of 9 simulation sets were created, each comprising 3 rendered images (**Fig. 5**), presenting variations in wall color schemes, color saturation levels, and brightness proportions, as illustrated in Fig 6.

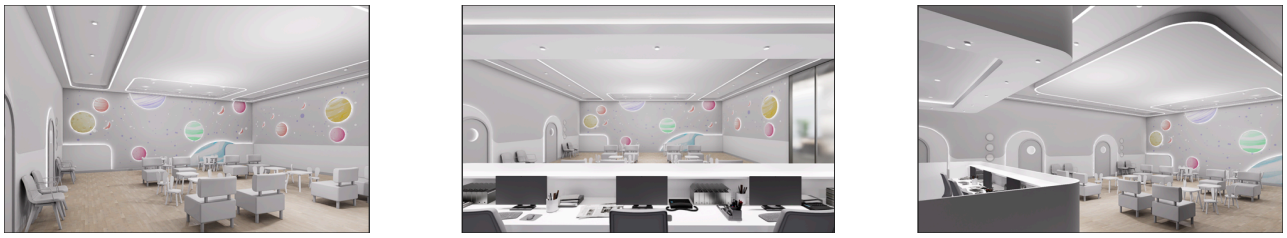

Fig. 5 - Simulated pediatric clinic environment in three perspectives (Source: Author)

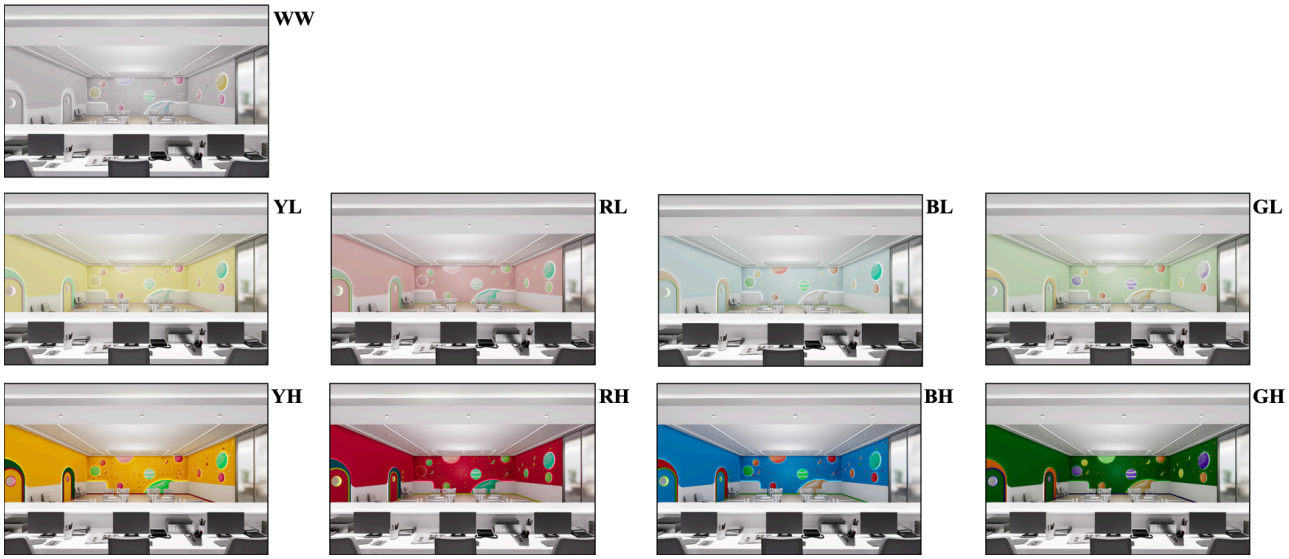

Fig. 6 - Simulated pediatric clinic environments in 9 formats. (Source: Author)

Participants were presented with 9 sets of simulated scene on iPad Pro 12.9-inch (6th Gen, 2022). This device features a Liquid Retina XDR mini-LED display with a resolution of 2732 × 2048 pixels, 264 ppi, and peak brightness of 600 nits. The survey environment was carefully controlled to ensure consistent ambient lighting, appropriate viewing distance, and minimal screen reflection. All sessions took place in rooms with neutral or white-toned walls to eliminate background color bias. Each participant was seated in front of the device and completed a structured six-part questionnaire within 20–30 minutes. The sections included: (1) demographic information (gender, age, work experience, job position); (2) the Ishihara Color Blindness Test (ICBT) to screen for color vision deficiency—those who tested positive were not excluded from participation but were omitted from data analysis; (3) Assessment of Individual Color Preferences; (4) the ST-5 stress assessment (Thailand's Department of Mental Health, 2024) to evaluate pre-existing stress levels within the past 2–4 weeks; (5) evaluation of satisfaction, arousal, and stress in response to the nine visual stimuli using both the Semantic Differential Scale and the Affect Grid; and (6) an open-ended question for additional reflections. Participants viewed each simulated image for approximately 10–15 seconds before completing the corresponding assessment. with the sequence of images randomized for each participant to minimize order effects and reduce potential bias. Data were analyzed using descriptive and inferential statistics. Means, standard deviations, and percentages summarized participant demographics, reported stress levels, and responses to simulated wall color schemes. Paired-sample t-tests were applied to examine differences in emotional perception and stress responses across color conditions. Pearson's correlation coefficient assessed the relationship between direct stress (Semantic Differential) and indirect stress (Affect Grid). This statistical approach ensured a consistent and focused evaluation of how different wall color schemes in pediatric clinics influence emotional responses and perceived stress levels among healthcare worker.

Results

A total of 45 participants took part in the study. The sample was predominantly female (n=36, 80.0 with males comprising (n = 7, 15.6%), and unspecified gender (n=2, 4.4%). The average age was 33.75 years, categorized into three age groups: 24–32 years (n=19, 42.2%), 33–41 years (n=17, 37.8%), and 42–50 years (n=9, 20.0%) The average work experience was 8.28 years. Regarding job positions, most participants were nurses (42.2%), followed by nurse assistants (26.7%), medical assistants (15.6%), doctors (13.3%), and others (2.2%). These proportions align with the typical workforce distribution in pediatric clinics, where nurses constitute the majority of personnel involved in child patient care.

Assessment of Individual Color Preferences shows that the most preferred colors were blue (33.3%) and green (20.0), while the least preferred were purple (13.3%) and black (11.1%). In terms of emotional associations, red (48.9%) and orange (46.7%) were most linked to arousal or alertness, while gray (57.8%) and white (44.4%) were associated with fatigue or sleepiness. Red (64.4%) were connected to anxiety or stress, whereas green (60.0%) were perceived as calming or relaxing.

Further analysis examined emotional and stress responses to nine simulated wall color schemes using a 9-point semantic differential scale across three bipolar adjective pairs. warm color (yellow, red) elicited higher arousal but lower pleasure and higher stress compared to cool color (green, blue). A significant difference was found between low-saturation (M = 6.92, SD = 1.56) and high-saturation scenes (M = 3.12, SD = 1.75), $t(179) = 23.37$, $p < .001$. Among the color schemes, light green (GL) recorded the highest pleasure (M = 8.02), while dark red (RH) had the lowest (M = 2.36). For arousal, RH scored highest (M = 7.56), and light blue (BL) lowest (M = 3.40). In direct stress assessment, GL was rated most relaxing (M = 7.51), whereas RH was linked to the highest stress (M = 1.96). The Affect Grid analysis showed a similar trend: BL yielded the highest relaxation (M = 7.57), and RH the lowest (M = 2.15). Statistically significant differences ($p<.05$) were observed between low- and high-saturation tones across all hues (e.g., GL vs GH), as summarized in Table 1.

Table 1. Mean, standard deviation, and correlation analysis of wall color schemes in pediatric clinic environments in relation to emotional responses and stress levels. (Source: Author)

Emotional Responses to Wall Color Schemes	White	Yellow		*Sig.*	Red		*Sig.*	Blue		*Sig.*	Green		*Sig.*
	WW	YL	YH		RL	RH		BL	BH		GL	GH	
	(S.D.)	(S.D.)	(S.D.)		(S.D.)	(S.D.)		(S.D.)	(S.D.)		(S.D.)	(S.D.)	
Pleasant – Unpleasant	4.60 (2.00)	6.11 (1.90)	3.93 (2.15)	0.000	7.40 (1.40)	2.36 (1.28)	0.000	7.98 (1.31)	3.58 (1.86)	0.000	8.02 (2.19)	3.02 (1.62)	0.000
Arousal – Sleepiness	4.36 (2.07)	5.36 (2.05)	6.49 (1.75)	0.007	4.44 (1.73)	7.56 (1.36)	0.000	3.40 (1.72)	6.38 (1.71)	0.000	3.93 (2.19)	5.80 (1.89)	0.000
Stressed – Relaxed[1]	5.16 (1.93)	6.87 (1.39)	3.80 (2.04)	0.000	6.29 (1.34)	1.96 (0.91)	0.000	7.00 (1.76)	3.78 (1.70)	0.000	7.51 (1.52)	2.96 (1.49)	0.000
Stressed – Relaxed[2]	5.27 (1.95)	5.40 (1.70)	3.79 (1.95)	0.006	6.58 (1.12)	2.15 (1.00)	0.002	7.57 (1.07)	3.44 (1.41)	0.011	7.27 (1.44)	3.42 (1.52)	0.037

1. Direct stress: Semantic Differential and 2. Indirect stress: Affect Grid (Pleasure–Arousal)

Fig. 7(a) shows the relationship between pleasure levels and wall color schemes by saturation. Results indicate that low-saturation colors yielded significantly higher pleasure across all hues. Light green (G) and blue (B) received the highest scores, while high-saturation red (RH) showed the lowest. Fig. 7(b) presents arousal levels, showing that high-saturation colors generally increased arousal, especially red (RH) and yellow (YH). In contrast, low-saturation blue (BL) and green (GL) were associated with lower arousal and sleepiness. Fig. 7(c) illustrates direct stress levels, which increased with color saturation. Low-saturation green (GL) and blue (BL) were perceived as most relaxing, while high-saturation red (RH) elicited the highest stress response. Fig. 7(d) confirms this pattern through indirect stress evaluation using the Affect Grid. Again, high-saturation red (RH) induced the most stress, while low-saturation blue (BL) and green (GL) were rated as most relaxing. Fig. 7(e) compares direct stress ratings (Semantic Differential) and indirect stress ratings (Affect Grid) across wall color schemes grouped by saturation. Direct and indirect stress levels were found to be strongly correlated, $r^2=0.95$, $p<.01$. The two methods showed strong consistency, with most schemes differing by no more than ±0.6 point. An exception was low-saturation yellow (YL), which showed a larger gap. Indirect assessments generally produced slightly higher stress scores, especially for high-saturation colors, but overall trends were aligned—indicating high reliability between the two methods in evaluating emotional responses to wall color in pediatric clinics.

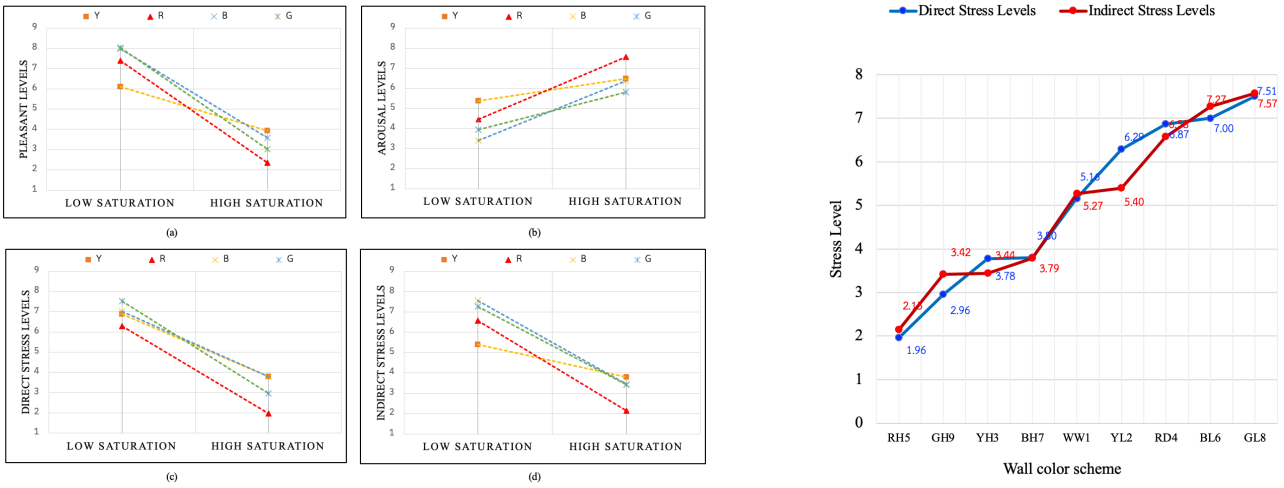

Fig. 7 - Relationships between wall color schemes in pediatric clinic environments and healthcare workers' emotional responses : (a) Pleasure–Displeasure, (b) Aroused–Sleepy, (c) Direct Stress Levels, and (d) Indirect Stress Levels. Relationship between the average scores of direct and indirect stress assessment methods. (e) *(Source : Author)*

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Conclusion

Compared with previous research, this study demonstrates several important differences. Firstly, instead of investigation on patients' and parents' perspective this research focuses specifically on healthcare professionals—a user group often overlooked. This research also adopts an experimental design in which the S–O–R model was applied, focusing on Stimulus (wall color scheme) and Organism (stress level). This research suggest that the 'Response' (aspects of Dominance, service selection decisions) should be further investigated for a more complete understanding. The findings demonstrated that wall color schemes significantly influence stress levels and emotional states among healthcare professionals in pediatric clinic environments. Low-saturation cool colors such as pastel green and light blue were found to reduce stress and support focus, while intense high-saturation warm colors like deep red and dark yellow were associated with hyper-arousal and emotional fatigue. Applying balanced design principles such as the 60-30-10 color proportion rule and color harmony can help create supportive work environments. Future research should include broader user groups such as patients, families, and support staff, and consider variables like emotional sensitivity, cultural background, and material qualities to advance evidence-based healthcare design. Finally, this study provides practical guidelines for pediatric clinics: low-saturation cool tones are recommended in waiting areas to reduce stress and support focus, while highly saturated warm colors should be avoided in work zones. Incorporating these findings into design standards can enhance supportive environments, improve staff well-being, and inform healthcare policies, with potential applications extending to other healthcare settings such as inpatient wards, pediatric ICUs, and staff workspaces.

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Color, Form, and States of Consciousness

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Abstract
This paper examines the relationships between colors and geometry in Tibetan Buddhism. In western thought, a hierarchy was established between color and form their use has been primarily for aesthetic purposes. In Tibetan Buddhism, however, colors have been recognized as energy and an inextricably related to one's body and mind as well as to the external natural world. Colorful geometrical forms have been painted, performed through dance and movement and visualized in reference to corresponding locations in one's body to transform ways of perception, thinking, feeling, and being in the world. Through close reading of Tibetan Buddhist texts, this paper provides an overview of the system and demonstrates through the two complex forms (mandala and double helix) how combination of color and form is associated with varying states of consciousness including non-dual awareness that is beyond subject-object distinction.

Key Words: color, geometry, Tibetan Buddhism, emotions, consciousness

Introduction

Interest in the relations between colors and emotions has emerged in the past century but through most western thought Western thought a duality was established between body and mind, emotions and logic. Followed by Aristotle who claimed that form is superior to color, both have been relegated to two opposing sides of the equation: the superior "form" has been equated with logic, while "colors," have been associated with the inferior body. Never shall the two meet, or rather, they must meet, but the relation between them has been taken to be arbitrary and not given due attention. Moreover, their use through most history has been mainly for aesthetic purposes and their relation to one's body has been almost completely ignored. This paper attempts to fill gaps in our knowledge by exploring the ways in which color and form combinations can used to shape physical constitution and varying states of mind.

The field of research and theoretical perspective in this paper is of Tibetan Buddhism and the method of research is close reading of Tibetan Buddhist texts and interviews with advanced teachers. Tibetan Buddhism is especially relevant for this research as it employs not only silent meditation but also colors in conjunction with geometrical to induce varying states of consciousness. From the monks' red robes to the use of hand movements known as mudras, to the intricate and colorful visualization of mandalas, chakras—colors and form play an important role in Tibetan culture and spiritual practice. A huge array of research found that these practices are not just conceptual – they improve concentration, compassion, happiness, well-being and physical health (Weaver et al, 2008; Gu et al, 2015). Advanced practitioners appear to also have skills in controlling their body temperature, feelings and dreams. This paper therefore explores a few combinations of color and form in different traditions of Tibetan Buddhism to deepen our understanding of their relation to body and mind.

Light and Colors in Tibetan Buddhism

In Tibetan Buddhism, colors are considered energy that is inseparable from the reification of the mind, one's body and the world. The process is explained in *The Six Lamps* and *The Mirror of the Luminous Mind* – two important texts from *Zhang Zhung Nyan* Gyud - the primary cycle of Dzogchen teachings, which is considered the highest path of practice in Tibetan Buddhism. According to these texts, five pure lights arise at the moment of conception in which pure awareness is still without identity. These lights are considered aspects of primordial luminosity and are more subtle than visible

light or energy felt, yet they are the energies from which all energies including visible light—arise. Consequently, they are associated with different states of awareness, and their ultimate and most subtle dimension is aligned with pure awareness that is nondual. If the five pure lights are perceived dualistically: as objects of the perceiving mind, they grow more substantial. While the lights themselves do not change, the individual perceives them as more gross until they are reified and become more distinct and materialize as the different colors and as dimensions of the external reality. Another way to understand it is that colors materialize as five essential elements (earth, water, fire, air, space) that can materialize in nature, but can also materialize internally to form the organs, the five senses, and branches of the body and emotions. When deluded, these lights and elements are associated with what Buddhists teachings call "five negative emotions" or the five poisons (anger or aversion, desire, jealousy, pride, and delusion). In a clearer state of mind, they can be associated with the five wisdoms (mirror like wisdom, equanimity, discriminating wisdom, all-accomplishing wisdom, and dharmadatu wisdom- the understanding of emptiness and interdependent origination). (Palzang, 2004).

The Bon teacher, Tenzin Wangyal emphasizes (2002) that the way in which the lights materialize is not a mythical or historical account, but explanation of different ways of being in the world. How one relates to the five pure lights as represented by colors is associated with different levels of awareness. When the five pure lights are recognized as a non-dual, unceasing manifestation of the pure basis of existence (*kunzhi*), nirvana begins. If the five pure lights are perceived dualistically and are thought to exist externally as objects -- then one is ignorant of the nature of consciousness and reality and the cycle of life-death and suffering ensues. The five pure lights can therefore be seen as means to practice with experience: subtle and gross.

Traditions of practice

Tibetan Buddhism is composed of mainly three traditions: external (shamanic), inner (Vajrayana also called Tantra) and Secret (Dzogchen). These traditions have different approaches to spiritual practice and therefore also to colors, forms, sounds and the elements associated with them. In the shamanic practices, these elements are associated with nature and other beings. In tantra, they are associated with more subtle energies and are manipulated through yogic practices involving posture, breathing, visualization, and mantras. In Dzogchen, the most subtle dimension of the elements is the radiance of being, the "five pure lights" aspect of luminosity that is united inseparably with emptiness. While these three paths of practice are separated conceptually, they are not mutually exclusive and can be practiced together.

The path of tantra is the path of transformation is especially important for exploration of work with energy through color and form. In this path, the nature of reality is described in terms of the inseparable union of bliss and emptiness. All practices therefore transform experience into bliss: physical sensations are turned into heat and pleasure, vision is transformed into divine visions, and sounds are transformed into mantras. The five negative emotions are transformed into five positive qualities, the physical body is transformed into a body of light and the suffering being is transformed into the enlightened Buddha. Tantra transforms experience with energy work: opening of chakras that are represented through colors and geometrical forms, unblocking energy channels that are also represented through colors, and activating the different pranas (energies) and mind aspect. This is done through a variety of yogic practices such as physical movements, breathing, visualizations and sounds. Colors are an essential dimension of these practices since they are conceived as energy, form is often added to activate particular experiences. For example, visualization of specific colors in coordination with the breath can balance certain energies and elements. Geometry is also used in conjunction with light and color to relate to the world in particular ways as well the body and mind.

Dzogchen, also called the great Perfection, is Tibet's principal tradition of gnostic mysticism. It describes itself as the pinnacle of attainment of Buddhist yoga, yet it also maintains distance from

traditional Buddhism at it is said to be beyond religious practice and immanent to human capacity (Dowman, 2007). Dzogchen teaches that the basis of all phenomena is inseparable emptiness and luminosity. Emptiness means that all beings and things have no essential, distinct identity. Entities exist yet their identity is not intrinsic but situational and transitory. Luminosity is both the concept as well as the sensual experience that best represents awareness. Emptiness and luminosity are considered here inseparable: emptiness is luminous and luminosity is empty. In Dzogchen, this is expressed as the capacity for endless manifestations of phenomena that are all essentially empty and luminous. According to Wangyal (2002), emptiness and luminosity can be represented as space and light. Emptiness is space out of which all phenomena arise and to which all phenomena cease. Light is the display of the five lights, the five elements, the manifestation of all things and all experiences. The revelation of the innate awareness that allows the light to shine out is called in Tibetan *rigpa* (Dowman, 2007).

Geometry, Colors and Consciousness

Colors and sounds are considered here energy and geometry is related to the pattern and order of experience. They are used in varying combinations, in relation to specific locations in the body to induce particular experiences and wisdom. In other words, by representing certain qualities such as emotions, states of physicality and mind through colors and forms, layers of connections between the world and one's self are perceived and knowledge on the nature of existence as emptiness and luminosity or emptiness and bliss can be experienced.

The most basic understanding and use of colors is in relation to what the most essential energetic qualities in the universe masculinity and femininity. The body in tantra is understood to be a network of energy channel and their activity is related to one's physical health and state of mind. The masculine channel (roma) begins in the left nostril in men, right in women, travels down the body, spiraling around the central channel, meeting at chakras. It is considered warm and activating, related to compassion, represented as white. The feminine Channel (Kyangma, rkyang ma) (left in women, right in men), begins in the left nostril, travels down in the same way, coiling around the central channel. It is associated with lunar energy, female principle, and wisdom. It is cool and receptive. This channel is seen as red. The central channel runs straight from crown of the head down to the base of the spine, just in front of the spinal column. It is associated with non-dual awareness when the winds enter it and it is represented as blue.

Another basic distinction between the colors is their relation to the elements as they manifest in nature and in the body (Wangyal, 2002, Tsulrim, 2018). Elements are associated with color, form, as well as aspects of experience such as sound and time. The associations manifest also in a more subtle way as related to the five senses, the five fields of sensual experience and the five extensions of the body. As body and mind are related, they are also related to thinking style and predominant emotions. Each element can be related to a certain way of being in balance, a situation which gives rise to the five wisdoms, or imabalnce and then manifest as the five wisdoms.

The five basic elements are: earth—symbolized as yellow, a square is and associated with solidity; water—white or blue, circle, cohesion and fluidity; fire – red , upward triangle, temperature and upward movement; air—symbolized as green, half-moon, movement, breath, life force; and space (white or blue) is the dimension that accommodates the other four elements, is represented as an empty sphere standing for infinite openness . In deity yoga or subtle yogic meditations, practioners work with the elements in specific body locations and learn to bring them into balance, to master them and then respectively transform the kleshas (aggregates of negative emotions) into balanced ones, hereby also gaining respective knowledge. Mastery over the elements therefore leads to control over emotions, karmic imprints and even shape our death and rebirth as these manifest as dissolution of the elements in a particular order.

Geometrical forms are used in varying levels of complexity. Some of the most basic symbolism are: a circle as representing wholeness and fluidity, half a crescent as movement, air and communication, squares as stability, upwards triangles as heat, fire and movement, lotus as purity, sphere as openness and inclusivity. Another commonly used shape is two traingles where upright triangle (pointing upward ▲) Symbolizes fire, transformation, the masculine principle, method (upāya), compassion, skillful means, and the dynamic/active aspect of enlightenment. The inverted tiangle (pointing downward ▼) Symbolizes water, receptivity, the feminine principle, wisdom (prajñā), emptiness, openness, and the receptive/insight aspect of enlightenment. When Combined (✡ or ⧖) they represent the union of wisdom and compassion (*prajñā* + *upāya*). The union of male and female deities in tantric iconography (yab-yum), the union of method and emptiness, which is the essence of Vajrayana practice. Geometrically, it forms a six-pointed star (hexagram) or a diamond-like shape, symbolizing inseparability. In Highest Yoga Tantra mandalas, interlocking triangles represent the mandala palace of deities — often a fire mandala at the center. In Chakrasamvara and Vajrayoginī practices, the double triangle is linked to great bliss and emptiness united. It is also related to the subtle body: fire at the navel (upward triangle) meeting nectar descending from the crown (downward triangle) and producing the non-dual realization.
The patterns are often joined together to create more complex forms such as representations of mandalas or chakras (energy centers located in the energetic body). In the following pages, I explain a couple of geometrical forms and their uses. They were chosen due to their significance in relation to altering state of consciousness. According to these traditions, the quality of experience is already inherent in the mind, but visualization enables its manifestation in the same way that light and irrigation can arouse the sprouting of a plant from a seed.

Mandala
Mandala is a sacred diagram, a visual symbol used especially in Vajrayana as a meditative aid representing the universe and one's mind. The term *mandala* originates in Sanskrit, but the Tibetan name discloses its geometric characteristic (Tibetan: *dkyil 'khor*, "center + circle"). Its structure is a circle enclosing a square palace, with four Ti shaped gates at the cardinal directions. Inside, appear other geometrical forms and enlightened beings. The design is highly symmetrical, expressing cosmic order and follows the golden ratio. Although it is represented on two dimensional surfaces as paintings, mandala is meant to be visualized and understood as a three-dimensional structure. While the mandala serves as a meditative aid when practioners visualize themselves in relation to it, it can also be used for healing and protection as talismans, for ritualistic purposes and as decorative art for example as thangkhas which are detached mandalas painted on cloth. Another famous use is sand mandalas traditionally created by monks for ceremonies and destroyed immediately after to illustrate the transitory nature of samsara (our world of illusions and suffering.)
The mandala represents the universe, both outer (cosmic) and inner (psychological) and it mirrors the structure of awakened consciousness as centered, harmonious and inclusive. At the center of the mandala resides a deity surrounded by a retinue of many enlightened beings who represent the nature of enlightened mind. Spiritual practice with a mandala often begins in a dualistic manner when the deity and the mandala are perceived as external to the practioner, but in non-dual traditions and more advanced stages of practice, the practioner sees oneself as the deity at the center of the mandala. The mandala embodies a fractal reality and reflects the relation between the outer and inner worlds, the microcosmos and macrocosms as expressions of one another. By entering the mandala, one moves from its understanding of an external universe to understanding one's mind and deepest awareness as inextricably related to everything else.
In its deeper and more detailed symbolism, the mandala appears in relation to the four cardinal relations, the five Buddha families, the five elements and accordingly to sense and bodily organs, imbalanced emotions and states of mind and then to their potentiality as balanced ones. These

conditions are related to the respective colors and forms. At the center of the mandala, represented as a blue sphere (in some traditions white) is the space element, which acts as a container that give rise to everything else that manifests from it. The relative Buddha family is Vairocana, the sense faculty is mind which is somatically expressed as mind and body cavities (mouth, nostrils, chest and abdomen). As the basis of all phenomena, imabalnced space element is expressed as the negative emotion (klescha) of ignorance but when transformed through practice it manifests as reality wisdom. Water element which is associated with fluidity and emotional energy is represented as white (or blue) and as a circle standing for unity and wholeness. It is associated with the Akshobya Buddha family and it appears in the east. The sense faculty related water is ear (sound) and the body organs associated with it are kidney, bladder and bodily fluids. The imbalanced emotion associated with water is anger which can be transformed into mirror like wisdom. In the west appears the element of fire as related to heat and energy and it is represented as an upward red triangle. The Buddha family is Amitaba, the sense organs are eyes (sight), the organs are metabolism, liver, body heat and digestion. The emotion arising from excess of heat is desire which can be transformed into discriminating wisdom. In the south appears the earth element which is associated with stability, grounding and abundance. It is represented as yellow and as a square. It is associated with the Ratna family, its sense organ is tongue (taste) and the organs are the most foundational aspects of the body: digestive system, bones, muscles and flesh. When the earth element is not grounded or balanced it manifests as pride, but when transformed it manifests as its opposite: equanimity or equality wisdom. The last element is the air element which is associated with subtle movement and communication and is represented as green and as a half crescent. It is related to Amoghasiddhi family, skin (touch), the respiratory and circulatory systems. Excess of air, or movement is related to envy, but when transformed it is expressed as an all-encompassing wisdom.

Many different sadhanas related to the mandala exist, but the mandala as a basic structure that represents the outer and inner reality is common to all of them. In terms of color research, the ways in which colors are understood as energies and their relation to respective emotions, the body and states of mind is essential. The view of tantric practices is gradual as certain states of mind are understood to be as negative and the visualizations of colors and forms amongst other things help to purify and transform them into enlightened states.

Non- Dual Forms and Practices

Dzogchen is a non-dual and non gradual approach to spiritual practice and its use of colors and symbols therefore changes. Geometrically, the inseparable emptiness and luminosity that is the true nature of all phenomena is represented in Dzogchen as a single sphere of pure light. It is single because it is non-dual, it has no boundaries or divisions, no inside or outside. Though it is non-dual, the elemental energies ceaselessly manifest in it. For this reason, it is often painted as a sphere of rainbow light made of the five elemental energies. Light is used as a symbol because it is the least substantial of all things perceived through the senses and because the nature of mind is said to be radiant and clear like light. All experiences appear in the light of awareness. When light as pure elemental energy meets awareness -- it reveals form. With dualistic awareness, meaning is projected into these forms and they are recognized as separate and independent and one ultimately projects feelings of longing towards certain forms or anger, hate and aversion towards others.

The long-life practice of Mandarava, which was discovered by the great Dzogchen master Chogyal Namkhai Norbu Rinpoche (2014), is aimed at promoting health and clarity awareness which is an enlightened state of mind. The practice begins with a mandala practice where one is at the center of the mandala and it follows various movements, mantras, and intricate visualizations with colors- most of them are meant to purify the elements and bring them into balance. After the purification, one visualizes all colors radiating from a seed syllable at one of the chakras and reflected back to it. At this stage, mantras swirl around the body in an interesting pattern: one circle spins counter clock-wise

around one chakra, while another circle spins clock wise around another chakra but both circles are connected and move in synchronicity. The use of colors in conjunction with the twisted form probably facilitate the movement from colors to light, distinction to unity, from dual to nondual perception. This shape, also known as the mobius ring does not often appear in common books summarizing Buddhist texts, but it was recently documented in scientific publications associating it with nonduality (Maimon, 2016) and in recent documentation of photon movement. It is important that the lights radiate from one's heart chackra and from one's naval chackra while they interact. The knowledge of heart and the knowledge of the gut, thus whirl together in an open-closed shape as the five lights are communicating with the outer universe.

Conclusions

In Tibetan Buddhism, colors and geometry are not decorative but but symbolic and functional. They are part of a sophisticated system of visualization practices, art, and ritual aimed at transforming perception and emotions, guiding practitioners toward enlightenment. This paper elaborated on a couple of forms known as mandala and the mobius ring and discussed the ways in which they can move knowledge of the self and the world into a more balanced and non-dual awareness. As these practices are vast and intricate and since they have been able to train many with success over thousands of years, much more knowledge can be gained from extricating and interacting with their insights in regards to color, forms and consciousness amongst other things.

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The Color of Creativity: From Bauhaus Theory to Digital Analysis

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Abstract

The Bauhaus movement's disciplined investigation of color as a technical and emotional device forever changed how art was understood in the early 20th-century. These legacy traditions are being extended in remarkable ways by new technologies today. This paper investigates how computational colour analysis of QuantumSpace extends the foundational theories of Wassily Kandinsky and exposes subliminal patterns in artmaking based on art-inspired mathematics of map of colour relations. We illustrate how modern technology is capable of deciphering the psychological aspects of the use of color in art, thereby pursuing the spirit of Bauhaus, as carried over into new realms of art authentication, preservation and the study of creative mind, through the analysis of Kandinsky's "Impression III (Concert Test)" (1911). Quantumspace technology makes use of 3D RGB color mapping, capturing the distribution of individual hues in volumetric space to form a psychological "color fingerprint" for a given artist. Results show that Kandinsky used a unique color volume consistently across works, even when particular hues varied the relationships among colors and the distributions of the colors in the luminosity spectrum are consistent. Further the artworks exhibit repetitive patterns in the use of blue landmarks as compared with the more restricted flavours of red. This study extends the methods of analysis developed at the Bauhaus, giving mathematical depth to color usability and chromatic patterns, therefore showing computational analysis to be capable of disclosing artistic patterns at the threshold of human perception.

Keywords: color theory, art psychology, Bauhaus, design history, chromatic psychology, digital humanities, art authentication.

Introduction : When Colors Tell Stories

In 1888, two revolutionary artists lived together in Arles, France. As Vincent van Gogh and Paul Gauguin shared a small yellow house, they also shared something less visible but equally profound: their approach to color. A recent computer analysis powered by the Quantumspace technologies over paintings from this period seems to reveal an astonishing fact, Van Gogh's style shifted slightly to include some of Gauguin's most common color schemes. The mathematical signature of their relationship seems to be hidden in the painting itself, barely perceptible to human eye for more than 100 years and then discovered by means of a sophisticated color mapping technique. This is just the beginning, soon we will unveil endless possibilities in how new technologies can reveal elements of artistic composition which even the original makers could have been unaware of. It represents a turning point in the evolution of color theory that began with the Bauhaus movement –continuing a journey from philosophical inquiry to mathematical precision while preserving the essential humanity of artistic expression.

From Philosophy to Algorithm: The Bauhaus Legacy

The Bauhaus school fundamentally changed how we think about the role of color in art and design. Established in 1919 by Walter Gropius, it was formed as a bold experiment that united artists and designers in the pursuit of radical new ways of fusing art, craft, and technology (Droste, 2019). One of its most important members, Wassily Kandinsky, theorized about the nature of color, stating that colors did not only serve as visual impressions but also were capable of exerting psychological forces in their own right, capable of evoking distinct emotional feelings.

"Color is a power which directly influences the soul," Kandinsky wrote in his 1911 treatise "Concerning the Spiritual in Art," developing a systematic approach to understanding how colors affect human psychology (Kandinsky, 1911).
What Kandinsky observed with artistic intuition, today's technology can now measure with mathematical rigor. Quantumspace technology, for instance, enables comprehensive analysis of an artist's creative signature, revealing how artists unconsciously embed personal elements through their color selection and mixing techniques, opening up a whole new field in analyzing artwork.

The Birth of Computational Color Analysis
QuantumSpace's journey began with a simple question: could an artist's mind be mapped through their artworks? Francesco Rocchi's foundational research explored the methodology for mapping an artist's cognitive patterns through artwork analysis, extracting behavioral data from brushstroke characteristics to determine physical painting habits and artistic methodology. This initial inquiry evolved into a sophisticated system extracting over three million data points from each painting.
The most direct information we can extract from raw pixels is the global color fingerprint. In its simplest form, this fingerprint consists of a count, for each color in the RGB space, of the number of pixels sharing that color within the image, regardless of their physical location on the canvas. In practice, however, we first normalize brightness and contrast to ensure meaningful results. In the reports the algorithm produces, visualizing this information in two ways: a 3D plot showing, for each color channel (red, green, and blue), the distribution of color intensity (Fig.1 – Impression III Concert Scatter Plot); and, what we call the color gem: the smallest 3D convex shape containing all the colors present in the artwork (Fig.2 – Impression III Concert Gem).

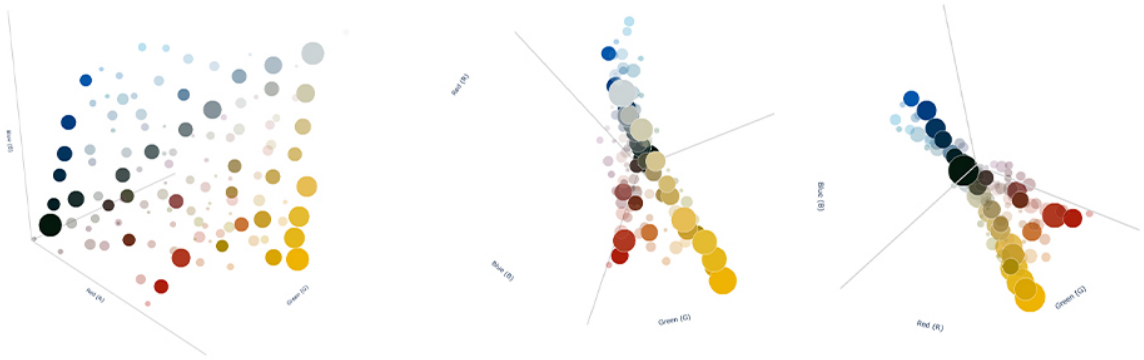

Fig. 1 – Impression III Concert Scatter Plot

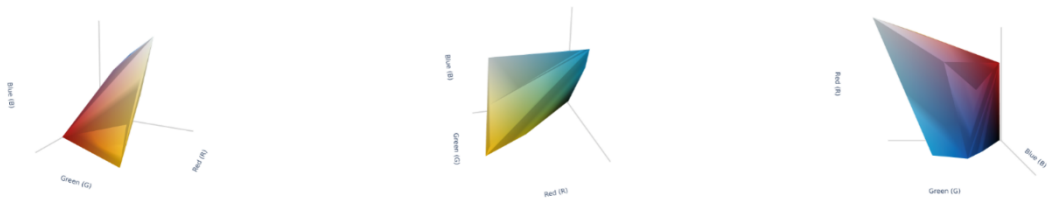

Fig. 2 – Impression III Concert Gem

Through Kandinsky's Eyes: 'Impression III Concert Test'

Take Kandinsky's 1911 "Impression III (Concert Test)" for example. Made at a critical moment in his evolution toward abstraction, this vibrant painting captures his emotional response to an Arnold Schoenberg concert that profoundly affected him. What makes this painting particularly significant, is that Kandinsky had synesthesia himself, a neurological phenomenon in which stimulation of one sensory pathway leads to automatic, involuntary experiences in a second pathway (van Campen, 2008). For Kandinsky, musical notes triggered specific color perceptions. The yellows, reds, and blues of "Impression III" weren't merely aesthetic choices but his literal visual experience of Schoenberg's atonal compositions. This painting represents a rare case where an artist documented his direct neurological response to sound through color (Ione and Tyler, 2004). QuantumSpace's analysis can thus reveal patterns in not just artistic choice, but actual sensory perception.

Computational analysis uncovers fascinating patterns in Kandinsky's use of colors. The most arresting colour is a vivid yellow (RGB: 241, 200, 54) dominating the right half of the composition. Mathematical analysis confirms what our eyes intuitively feel – this yellow creates an immediate focal point, drawing the viewer's gaze and radiating energy throughout the piece.

The three largest colours in terms of area used in the design are shades of yellow (hex code: #F0B503, #E9C03C, and #E6B81C) and make up 35.8% of the canvas in total (12.08%, 11.19%, and 12.54% respectively). However, when we look at the scatter plot we can see a surprising aspect of Kandinsky's use of blue. Yellows may prevail by surface, but Kandinsky's blues are many and subtle – there are far more of them than his reds, which are still confined to very precise shades.

The analysis reveals Kandinsky's selective color palette approach: a restricted red spectrum utilizing specific preferred tones, contrasted with an extensive blue spectrum demonstrating deliberate chromatic exploration. This selective approach to color range – expansive in blues, restricted in reds – creates a particular psychological tension invisible without computational analysis.

Perhaps most remarkably, when these colors are mapped in three-dimensional space, they create a distinctive volumetric shape, what QuantumSpace calls the "color gem." Somehow this form stays the same for Kandinsky in this period of his art even though the actual colors differ. It's like a type of psychological fingerprint, specific to the artist that can be found as consistent through his production (Fig. 3 - Kandinsky's production color usage).

The most astonishing fact is that across multiple artworks, this space does not change (Fig. 4 - Kandinsky color trends and shading patterns). Even if the colors change inside the painting, the space within they are included remains the same. This consistency becomes not only an invaluable asset for educational purposes but also a powerful authentication tool; when a supposedly authentic painting shows colors outside this characteristic volume, it immediately raises questions.

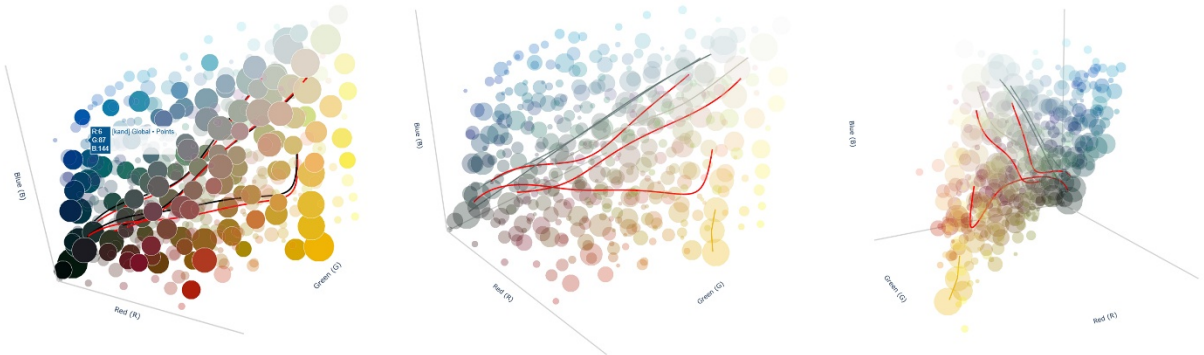

Fig. 3 – Kandinsky's production color usage

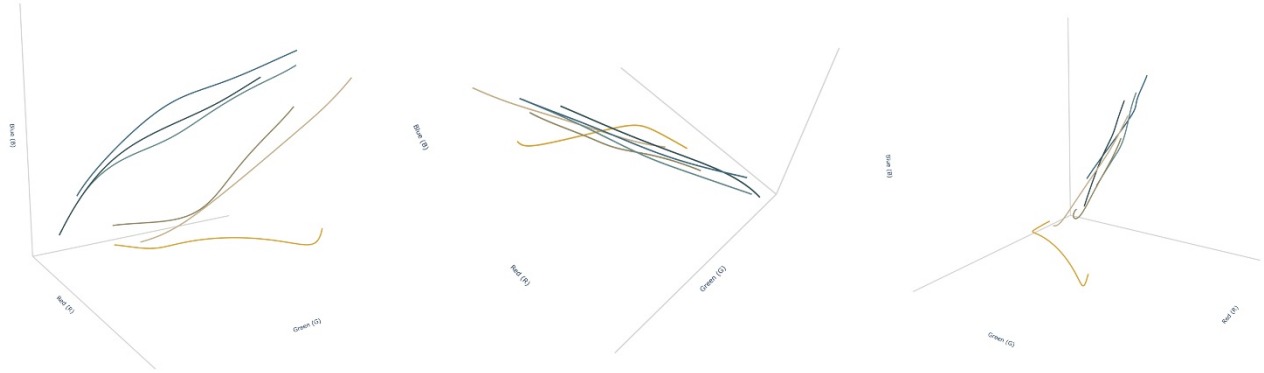

Fig. 4 – Kandinsky color trends and shading patterns).

Beyond Authentication: New Ways of Seeing

While authentication applications are compelling, the technology's ability to reveal the psychology behind artistic choices may be its most profound contribution. The analysis shows how Kandinsky's distribution of highlights (24.66%), midtones (47.88%), and shadows (27.95%) creates a balanced visual rhythm peculiar to his work.

More intriguing still are the "eye catching" places - regions where the mathematical model suggests that the audience's attention will settle. In the "Impression III Concert Test," one especially brilliant red accent is entirely independent from the painting's main color associations.

It is something that our mind tells us subconsciously, but now we can have a scientific reason for it, a series of numbers describing the relations between that specific color and the rest of the painting. This mathematical validation of artistic hunches exists between the realm of science and creativity and gives a solid and clear description to every single element of an artwork.

The technology transforms how we experience art, making it interactive and immersive but also measurable. Users can explore every detail, uncovering nuances that are invisible to the naked eye and confront color relations and compositions across multiple productions.

Conclusions: Continuing the Bauhaus Vision

The Bauhaus school aspired to integrate art, craft and technology, and to dissolve the boundaries between creative practices. QuantumSpace carries on that tradition, applying mathematical rigor to aesthetic understanding without robbing art of its emotional force, it is new light to explore the depths of the artistic research with a better grasp on its single components. The study of color started thousands of years ago, the Bauhaus gave philosophical structure to it, and these new technologies are now building over what other people did before them. We are moving towards a future where the mystery of art will be explored like never before, merging philosophy, psychology and data science to map the components of creativity itself.

This method carries on the Kandinsky legacy by continuing the analytical tradition he could have only dreamed was possible at the time. In probing these new frontiers of color analysis, we discover that we live up to the promise that his theories suggest , that color is not merely a visual element but a dramatic theme that stretches our minds to give us a view of the events of the world.

Funding Sources

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Can the adaptive colour shift help detect incomplete chromatic adaptation?

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Abstract

Following the definitions of the CIE ILV (CIE S 017:2020): the adaptive colour shift is the change in the perceived colour of an object caused solely by a change of chromatic adaptation (the visual process whereby approximate compensation is made for changes in the colours of stimuli, especially in the case of changes in illuminants). Incomplete adaptation is the phenomenon in which the adopted white (colour stimulus that an observer who is adapted to the viewing environment would judge to be perfectly achromatic and to have a luminance factor of unity) in a given viewing environment does not actually appear white to an observer.

The main question of the presented study was whether it's possible to differentiate complete and incomplete chromatic adaptation based on achromatic settings. To observe the changes in the perceived white under different states of chromatic adaptation, subjects had to adjust chromaticity on a digital screen to set an achromatic stimulus.

The long-term goal of the research involving the presented study is to build a framework for collecting data from various experimental settings, leading to a universal chromatic adaptation model. The initial results indicate the relation between the achromatic colour settings and the state of chromatic adaptation.

Keywords: Chromatic adaptation, Adaptive colour shift, Adopted white, Incomplete adaptation.

Introduction

LEDs' technological developments bring changes in lighting technology and in the field of digital displays. Expanding and refining chromatic adaptation models considering changes in the characteristic spectral contents is advisable. The methodological goal of the research involving the presented study is to build a framework for collecting data from different experimental settings, which leads to a universal chromatic adaptation model.

The main questions of the research involving the presented study are the followings:

1. How can the state of chromatic adaptation be quantified?
2. What metrics can be used to characterize the degree of adaptation?
3. What photometric environment, devices, and methods are necessary for a well-founded determination of the state of chromatic adaptation?

Chromatic adaptation refers to the continuous adaptation of our visual system to the changes of the surrounding lighting conditions: while the color of the illuminated environment changes, the visual system adapts to this change referring to retinal signs. As a result, the perceived color of objects remains unchanged or similar. If chromatic adaptation is not complete, *i.e.*, the color of the objects changes simply due to the change in the state of chromatic adaptation, we speak of adaptive color shift.

The modeling of chromatic adaptation is an active field of research at international level. Even though the first chromatic von Kries transform was defined in 1905, initial color appearance models mainly dealt with white and light-colored lighting environments, and the degree of adaptation was primarily defined as a function of luminance. In the last decade, research that also takes into account the color of the adaptation environment has been published (Fairchild, 2013, 2020; Huang et al., 2018; Ma et al., 2018, 2020; Smet, 2018; Smet et al., 2017).

Following the definitions of the International Lighting Vocabulary (CIE S 017/E:2020 - ILV, 2020): Chromatic adaptation is the visual process whereby approximate compensation is made for changes in the colours of stimuli, especially in the case of changes in illuminants. Adapted white is the colour stimulus that an observer who is adapted to the viewing environment would judge to be perfectly achromatic and to have a luminance factor of unity. Incomplete adaptation is the phenomenon in which the adapted white in a given viewing environment does not actually appear white to an observer.

Therefore, in understanding and describing the state of adaptation – the state of the visual system after an adaptation process has been completed – the relationship between the achromatic colour stimulus, the achromatic colour sensation, and the achromatic perception plays a prominent role.

During the investigation of the adaptive colour shift, the primary objectives are the observation of color appearance and color identification. In the study of chromatic adaptation, particular emphasis is placed on the relationship between the white in terms of colour stimulus, psychophysical colour and perceptual colour. The first main question is therefore:

Which chromatic stimulus is perceived as achromatic - or white - under a given state of adaptation?

Only after gaining an understanding of the variation in perceived whiteness does, it becomes meaningful to investigate the adaptation-induced chromatic shifts across the full spectrum of perceivable colors.

Preliminary studies suggest that the chromatic characteristics of the adapting environment influence the local minimum of chromatic discrimination thresholds. A key goal of this study is to support this observation through the analysis of perceived white.

The expected outcome of the research is the development of a framework for collecting data across various experimental conditions, ultimately contributing to the construction of a universal model of chromatic adaptation. The comprehensive experimental design aims to incorporate current scientific findings, with particular attention to relevant parameters and their appropriate ranges of investigation.

Methods

The basis of examining adaptive colour shift is primarily colour appearance and colour identification. In the presented experiments the task was to display achromatic colour on a digital display in a specific adapting environment. In addition, measurements of chromatic discrimination were executed applying the Cambridge Colour Test.

States of chromatic adaptation

The controlled states of chromatic adaptation were accomplished by coloured lenses (Fig.1) or in a spectrally tunable light booth (Fig.2). The transmission spectra of the lenses can be seen in Fig. 3.

Fig. 1 – The coloured lenses applied in the experiments

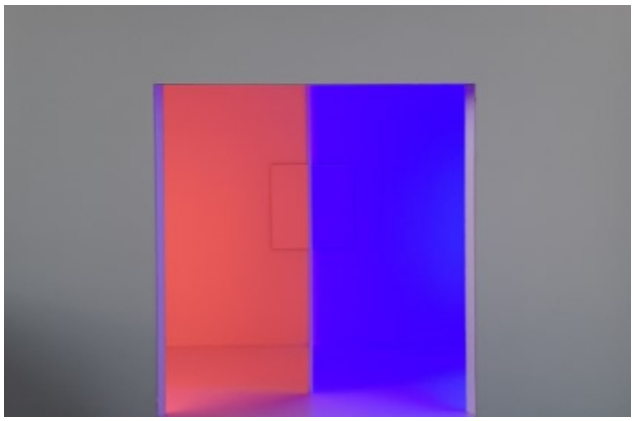

Fig. 2 – The spectral light booth applied in the experiments

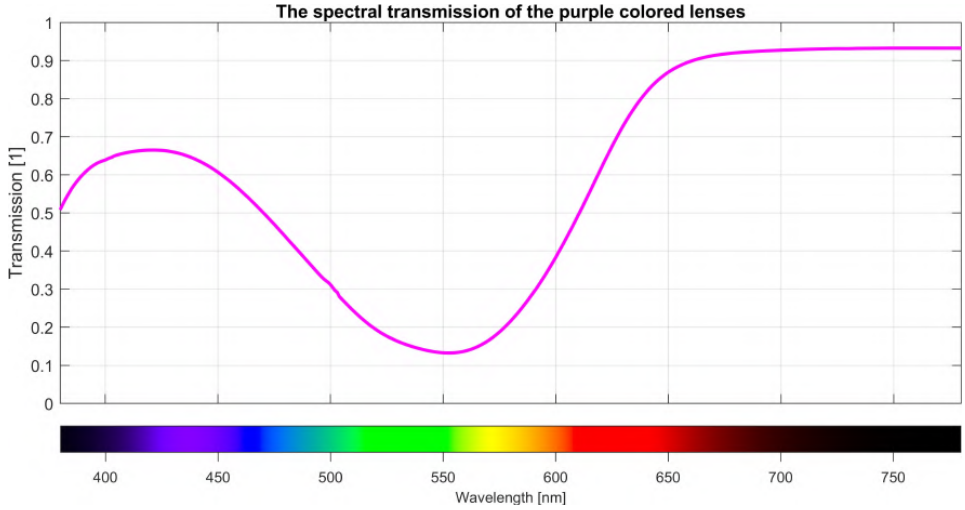

Fig. 3 – Spectral transmission of the applied coloured lenses

In case of measurements wearing the glasses, subjects had 3 minutes to start adaptation with lights on. Measurements were carried out in a dark room after a short dark adaptation. When measurements were carried out in the light booth, subjects had 3 minutes to adapt to the lighting environment provided by the booth.

Measurements

Adaptive shift was observed via achromatic settings on a digital display either using a custom-made software, developed for the ViSaGe MkII system or using a custom-made software developed for a tablet, or a simple colour mixing app available for a tablet. In each case, initial stimulus was randomized.

In the test developed for ViSaGe, the size of the adjustable stimulus was equal to the size of the test figure of the Cambridge Colour Test, to make results comparable with the results of the Cambridge Colour Test. Subjects had to repeat settings achromatic stimulus as many times as they could in three minutes.

Chromatic discrimination was observed by measuring the just-noticeable stimulus with the Cambridge Colour Test. Cambridge Colour Test is a display-based pseudoisochromatic test (Hasrod & Rubin, 2015; Mollon & Regan, 2000; Regan et al., 1994) that provides the just-noticeable stimuli as result in defined directions from a reference point. The native chromaticity diagram of the test is the CIE 1976 UCS diagram. Subjects performed the trivector test in which three directions are defined towards the three confusion points. Reference points defined the chromaticity of the background while the chromaticity of the Landolt-C pattern changed on the three confusion lines to find the three thresholds.

In the experiment the reference points were varied between measurements, while the confusion points were fixed to the values seen in Table 1.

Table 1 – The u'v' chromaticity coordinates of the Protan, Deutan and Tritan confusion points applied in the experiment

	Protan	Deutan	Tritan
u'	0.6579	-1.2174	0.2573
v'	0.5013	0.7826	0

Reference points (see Table 2) were selected based on former experiments, were chromatic discrimination thresholds were measured with unaided eyes (Urbin & Nagy, 2021).

Table 2 – The reference points of the Trivector tests applied in the experiment

	-64	-63	-62	-61	60	61	62	63	64
u'	0.2784	0.2594	0.2404	0.2214	0.2024	0.1834	0.1644	0.1454	0.1264
v'	0.3930	0.4119	0.4310	0.4499	0.4689	0.4879	0.5068	0.5258	0.5448

Reference measurements were accomplished with unaided eye in reference points -64, 60 and 64. Viewing distance was approximately 5 meters from the display in all cases. Luminance levels varied between 6 to 20 cd/m^2 in case of wearing the glasses and between 2 and 8 cd/m^2 in case of unaided eyes.

Results

Among the pilot studies the results of the one carried out with coloured lenses and the custom-made application developed for the ViSaGe MkII system are shown.

The distributions of the just-noticeable stimuli were approximated with quadratic functions. The minimum points of the functions indicate the chromaticities around which chromatic discrimination occurred the best. In Fig.4 the red, blue and green markers indicate the local minimum points of the chromatic discrimination thresholds towards the Protan, Deutan and Tritan confusion directions, respectively.

White dots indicate the achromatic settings with unaided eyes, and the black dots indicate the achromatic settings wearing the coloured glasses.

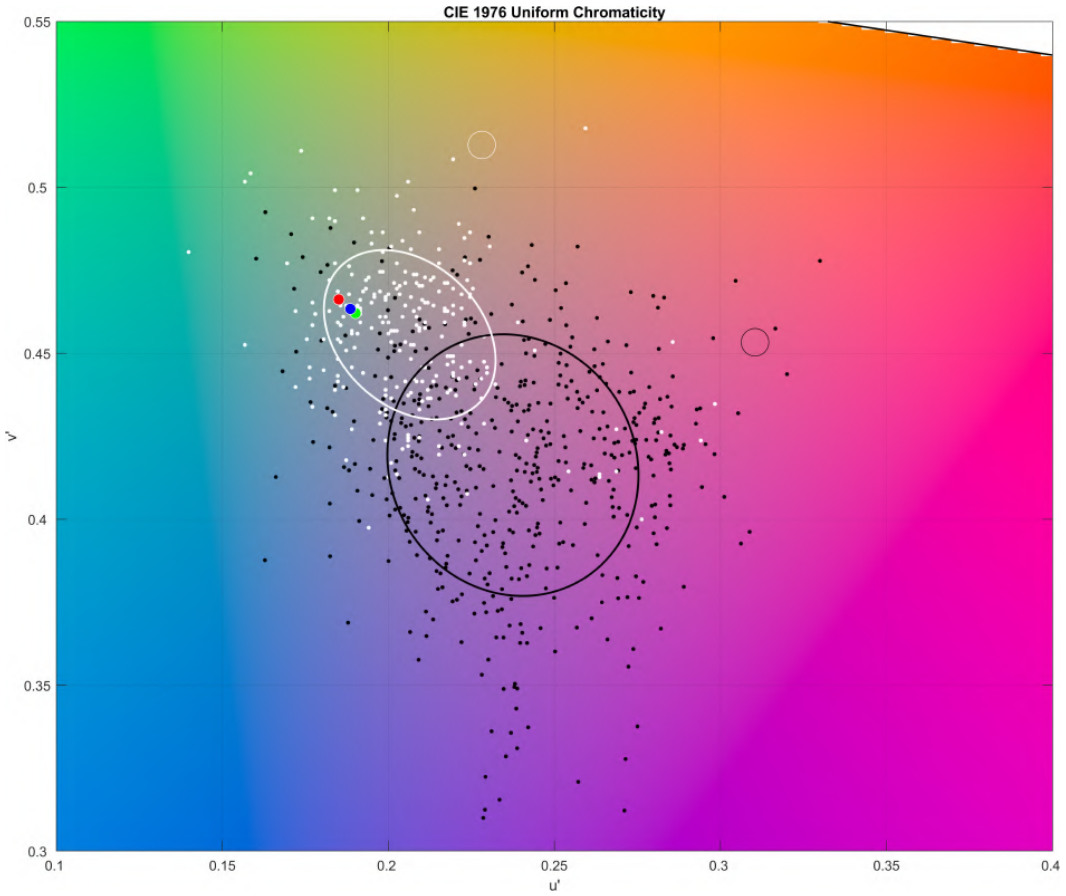

Fig.4. – The approximated chromaticities where the smallest chromatic discrimination thresholds occurred (red - Protan, green - Deutan, blue – Tritan confusion direction), and the achromatic settings with unaided eyes (white) and wearing the coloured glasses (black).

Initial results show the difference between the achromatic settings in the different states of chromatic adaptation. Subjects did not report full adaptation – white objects appeared to be less chromatic with time, but not perfectly achromatic, that suggests incomplete adaptation. Even though, the estimated best chromatic discrimination was not shifted along with the achromatic settings.

Further measurements are necessary to define the degree of chromatic adaptation and the relation between the adaptive shift and the changes in chromatic discrimination.

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Color and Restoration

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"Il Borgognone" or his school? Assessing a 17th-century painting attribution through multi-analytical investigations

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Abstract

This study presents a multianalytical investigation of a canvas painting depicting a battle scene, tentatively attributed to Jacques Courtois, known as "Il Borgognone" or the artists of his school (17th-19th century), with the aim to verify or reconsider the painting's attribution. The artwork belongs to a private owner. The research combines non-invasive Raman spectroscopy (using a Bruker Bravo portable spectrometer with dual excitation wavelengths: 785 nm and 852 nm) and VIS-NIR hyperspectral imaging to identify the pigment palette and map its distribution across the painting. This integrated approach provides insights into the artist's layering techniques, color application methods, and overall chromatic composition. The collected data were systematically evaluated to correlate pigment selection and painting style with the documented artistic practices of Courtois and his followers. Comparative analyses were conducted on works already attributed to the master or his workshop to examine the pigment palette and execution techniques. This methodological approach not only complements expert art-historical evaluations but also provided objective technical evidence supporting the attribution.

Keywords: Historical pigments, diagnostics, artwork attribution, canvas painting, Il Borgognone, Raman spectroscopy, MicroNIR, hyperspectral imaging.

1. Introduction

The correct attribution of a work of art is essential not only for its cultural and economic value but also for guiding conservation strategies and ensuring its historical and artistic contextualization. Typically, identifying the artist or the school of origin requires in-depth stylistic and technical analysis, increasingly supported by multidisciplinary scientific investigations (Armetta et al., 2023). This approach is particularly valuable in the absence of historical documentation, when records are fragmentary, or when traditional attributions remain uncertain or contested (*Saladino et al. 2022*). Within this framework, the present study focuses on a privately owned oil on canvas painting depicting a dynamic battle scene. The work has been tentatively attributed by experts (Fig.2) to Jacques Courtois, known as Le Bourguignon (1621–1676), or to an artist belonging to his school, active between the 17th and 19th centuries (**Pignatti, 1960**). Courtois, a French painter active in Italy, is renowned for his realistic depictions of battles and his distinctive palette, characterized by natural earths, mineral pigments, and chromatic highlights, applied with exceptional technical skill. His compositions were frequently replicated or imitated by pupils and workshop assistants, which makes it particularly challenging today to distinguish autograph works from later productions. This study represents the first analytical investigation conducted on this painting and aims to assess the validity of its attribution through an integrated diagnostic approach combining portable Raman spectroscopy, MicroNIR and VIS-NIR hyperspectral imaging. These non-invasive techniques allow for the identification of the pigment palette used by the artist and provide insight into the painting's execution technique. The data collected were compared with those from works definitively attributed to

Courtois and his circle**,** to identify significant similarities or discrepancies**.** This research is part of a broader diagnostic project aimed at analyzing other artworks attributed to the same artist or his school, with the goal of more precisely defining the technical and stylistic features of the battle painting tradition. As part of this wider initiative, XRF investigations will also be carried out in subsequent phases of the project. The battle painting tradition gained widespread popularity throughout the seventeenth and eighteenth centuries, evolving into a well-established artistic practice that featured prominent artists such as Vincent Adriaenssen, Francesco Monti, Ilario Spolverini, Salvator Rosa, and others (**Consigli Valente, 1986**)**.** These works were especially prized by both the aristocracy and the urban bourgeoisie, who commissioned them to decorate picture galleries and formal reception rooms. Given the high demand, such paintings were frequently produced in large quantities, sometimes in series, and were widely imitated or copied (**Succi, 2014**). For this reason, many surviving examples lack a clear attribution and are rarely signed, making the task of attributing authorship particularly complex. The painting examined in this study (Fig.1), belonging to a private collection and inherited by the current owner, is unsigned but presents several distinctive stylistic features that align closely with the school of Jacques Courtois, known as Il Borgognone, and could be attributable to the artist himself. Importantly, in the late 1950s, the work was subjected to a formal expert appraisal. The original expertise report (Fig. 2), authored by Umberto Ronchi (†1994), an art critic active in Bergamo from the 1940s to the 1980s, and preserved in the owner's family archive, explicitly attributes the painting to Il Borgognone or its school. Particular attention will also be devoted to the works of Salvator Rosa, a contemporary painter likewise active in Italy and associated with the same thematic and stylistic current, well known for his dramatic and animated compositions, often centered on martial subjects. Several of his works are held in the collections of prominent museums and galleries with which the authors actively collaborate. A comparative study of the techniques and materials employed by these artists will offer a significant contribution to the accurate attribution and deeper understanding of artistic practices in the period.

Fig. 1 *The Battle Scene,* a 108 × 152 cm canvas painting from a private collection in Messina (Italy), features the marked measurement points**.**

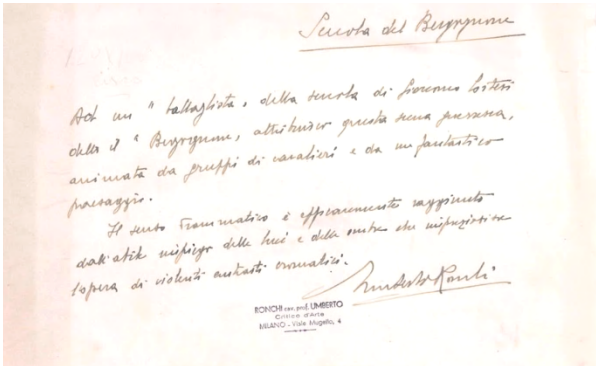

Fig. 2 The figure shows the original appraisal conducted in the 1950s by the art critic Prof. Umberto Ronchi.

2. Materials and methods

2.1. Painting Under Study The subject of this investigation is an oil painting on canvas, measuring approximately 108 × 152 cm, depicting a large-scale cavalry battle populated with numerous figures, horses, smoke, and architectural elements in the background. The painting is unsigned and undated, but its style is consistent with 17th-century battle scenes. At least one documented restoration was carried out during the 20th century, involving surface cleaning and partial reintegration of paint losses. The artwork is generally in good condition, although localized craquelure, areas of overpainting, and residual varnish are present. Stylistic analysis and a previous expert appraisal have tentatively associated the painting with the oeuvre of Jacques Courtois or his immediate circle, thereby highlighting the need for a more objective, science-based investigation.

2.2 Multianalitic approach A multi-analytical approach was employed to investigate historical paintings, combining complementary techniques to obtain comprehensive information on their material composition, stratigraphy, and state of preservation. This methodology enhances diagnostic accuracy while promoting sustainability, as it minimizes sample collection, reduces the need for invasive analyses, and ensures a more efficient use of resources during the examination of these delicate artworks.

2.3. Raman spectroscopy The analyses were conducted using the BRAVO handheld Raman spectrometer from Bruker, which features the DuoLaser™ technology (the technical feature of this device and its application for historical pigments is described by Innocenti et al. 2024). This device incorporates the patented SSE™ (Sequentially Shifted Excitation) technology, specifically designed to reduce fluorescence interference (Giuffrida et al. 2021). It utilizes two excitation lasers with central wavelengths of 785 nm and 852 nm that operate in coordination to limit fluorescence effects. Although both lasers contribute to the signal, the experimental configuration did not allow their individual contributions to be isolated. The spectrometer was connected to a dedicated computer, where measurement parameters were configured using Bruker's OPUS software—an option not available directly on the handheld device. This software also allowed real-time visualization of spectral data and automatic comparison with an integrated reference library. For compound identification, the collected spectra were matched with entries from open-access databases such as IRUG and Public Spectra.

2.4. MicroNIR The MicroNIR spectrometer, developed by VIAVI Solutions Inc. (formerly JDSU Corporation, Milpitas, CA, USA), is a cutting-edge device designed for rapid, on-site analysis of a wide variety of materials. One of its main advantages is the ability to perform measurements without the need for laborious sample preparation. The instrument operates within the near-infrared range of the electromagnetic spectrum, specifically from 900 to 1700 nm, and data were acquired using a nominal spectral resolution of 6.25 nm. For each sampling spot, five measurements were acquired. Before analysis, the spectrometer was calibrated using dark and blank scans.

3. Hyperspectral camera

Hyperspectral data were acquired using the HERA VNIR system (NIREOS), a compact and robust imaging device based on a patented Fourier Transform (FT) spectroscopic technique operating in the range from 400 – 900 nm. The system incorporates an innovative common-path birefringent interferometer (CPI), derived from a modified version of the GEMINI interferometer, integrated with a standard objective lens and a two-dimensional imaging sensor (Amigo J.M. *et al* 2015, Picollo, M. *et al.*2023). Hyperspectral data are collected as a time-domain data cube, formed by acquiring a series of monochromatic images at sequential optical path differences introduced by the interferometer. The final spectral cube is reconstructed by applying a Fourier Transform to each pixel in the image sequence. Owing to its high sensitivity, spectral precision, and ability to operate under low illumination, the HERA VNIR system is particularly well-suited for cultural heritage applications, including artwork authentication, conservation monitoring, and material characterization through non-invasive analysis (**Pelosi et al., 2020**). In the context of the present study, Fig.3 shows a representative hyperspectral image that illustrates the spatial distribution of the pigments employed in the painting.

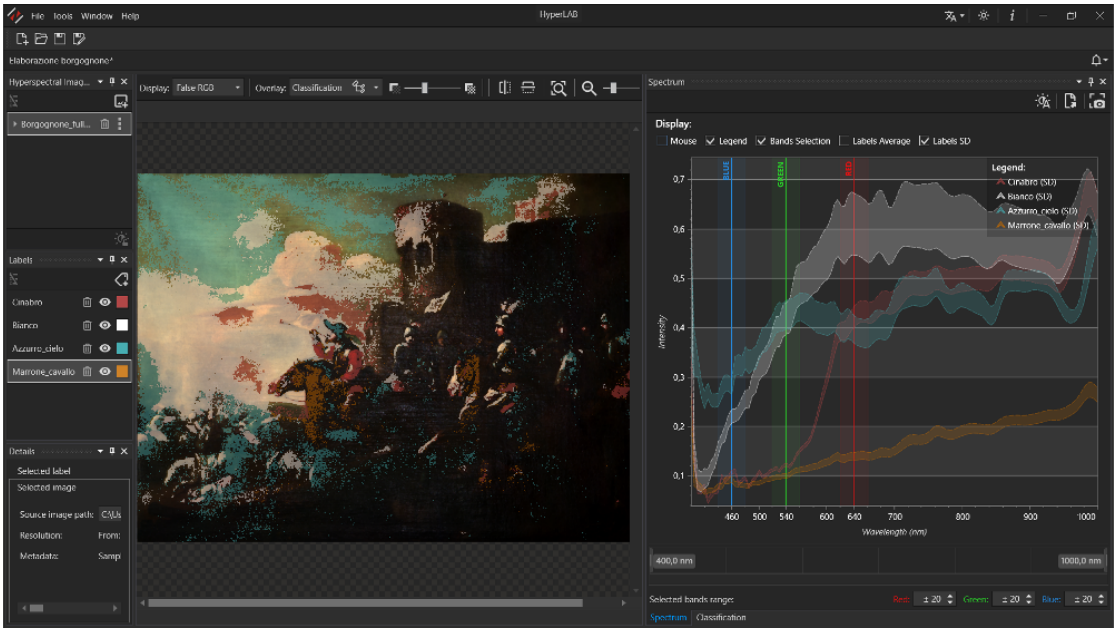

Fig. 3 *Hyperspectral image acquired using the HERA VNIR system (NIREOS), operating in the 400–900 nm range, showing the spatial distribution of the pigments in the painting*

Macro-photography documentation For the lacunae and/or detachment areas (Damage Areas A, B, C), detailed macro-photographs were taken. A Canon EOS M3 digital camera equipped with a Sigma 70 mm f/2.8 macro lens was used for this purpose. This setup enabled precise observation of minute surface features. The camera was mounted on a sturdy tripod to ensure sharp and stable images. Directional lighting from one or more sources was adjusted to enhance morphological variations, textures, micro-lacunae, and other significant details present in the small areas of the artwork.

Point	Color	Position	Location
1	Red	Sleeve	Central rider in the foreground
2	Blue	Feather on the hat	Central rider in the foreground
3	Light blue	Sky	Area above the tower, near the clouds

4	Orange-brown	Saddle	Horse of the rider on the right
5	Orange	Feather on the hat	Central rider in the foreground
6	Brown	Neck	Horse in the foreground on the left
7	White	Cloud	To the left of the tower

Table 1 - Table 1. Measurement points in Fig. 1: each point corresponds to a distinct color field, position, and location in the painting.

4. Results and discussion

The multi-analytical investigation of the painting enabled the precise identification of the artist's pigment palette, confirming the use of historical materials consistent with 17th-century painting practices and compatible with the working methods of Jacques Courtois (Il Borgognone) and his school. The red pigment used on the sleeve of the central rider in the foreground (Fig.4) was identified as cinnabar, a mercury sulfide (HgS) mineral pigment widely employed in antiquity for its intense and brilliant hue. Its selective use, often reserved for central figures or focal elements, aligns with chromatic strategies observed in authenticated or workshop-related works by Courtois school.

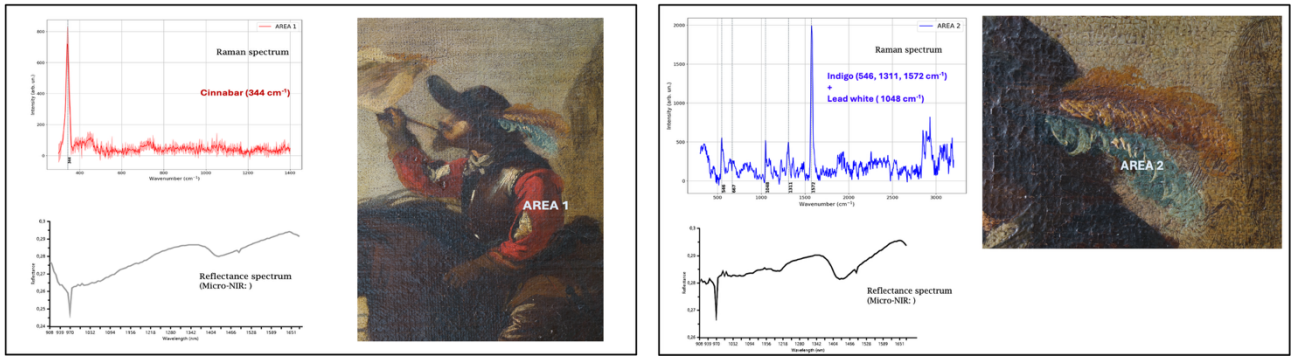

Fig. 4 Detailed views of Area 1 and Area 2 of the painting, with Raman and MicroNIR spectroscopic measurements.

The blue of the sky, composed of a combination of lead white and Prussian blue (Fig.5), reveals a superimposition of materials that may suggest a later intervention or a subsequent painting phase. Considering that Prussian blue only became available after 1704, its presence may suggest a later retouching campaign or the involvement of a subsequent workshop, consistent with the documented activity of Courtois's followers in the ensuing decades.

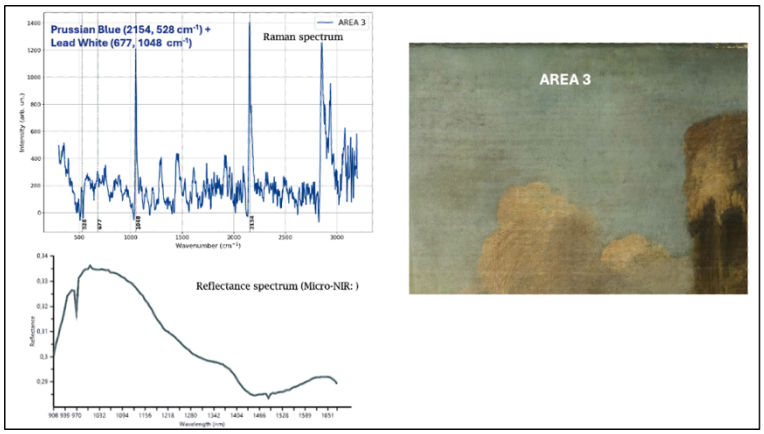

Fig. 5 Detailed views of Area 3 of the painting corresponding to the blue of the sky, with Raman and MicroNIR spectroscopic measurements.

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As for the light blue feather (Fig.4), the identification of indigo mixed with lead white points to a deliberate material choice aimed at achieving soft, cool tonal variations. Indigo, an organic dye of vegetal origin, was commonly used in the 17th century, particularly for shading and glazing. Its presence is fully consistent with the layered techniques documented in other paintings attributed to Courtois. The brown tones observed in both the feather and the horse's neck were associated with a mixture of cinnabar and an unidentified brown pigment, likely raw or burnt sienna. This chromatic selection reflects a nuanced approach to modeling volume and depth through warm tones, a technique also seen in the work of contemporaries such as Salvator Rosa, who was also active in battle scene painting. Overall, results from Raman spectroscopy and hyperspectral imaging confirm the use of diverse palette comprising both mineral and organic pigments, applied in a manner consistent with known 17th and 18th century painting techniques. However, specific elements, most notably the presence of Prussian blue in the sky, may, with due caution, be interpreted, as the result of a restoration campaign or to a later intervention by an artist associated with the Borgognone school.
Prussian blue functions as a diagnostic marker for post-early eighteenth-century interventions. Historical sources place its invention in 1704 and early dissemination between 1710 and 1721 (**Bartoll, 2008**); therefore, any paint strata containing this pigment cannot predate the eighteenth century. This aligns with technical literature that treats Prussian blue as the first fully modern synthetic pigment and a reliable chronological indicator in Western paintings.
A preliminary hyperspectral analysis was carried out as part of the diagnostic study on the painting (Fig.3). The left panel highlights four pigment classes: cinnabar (red areas), white (light regions, including clouds and highlights), sky blue (blue areas of the sky and feathers), and brown (horse) (warm-toned regions such as the horse's neck and mane). The segmentation clearly distinguishes between these pigment types, allowing for the mapping of their spatial distribution. The right panel presents spectral plots showing the mean reflectance curves (with standard deviation) for each pigment class, covering the visible to near-infrared range (400-1000 nm). The distinct spectral signatures confirm the separability of the identified pigments, particularly the high reflectance of white pigments across the spectrum, the characteristic absorption of blue pigments in the red region, and the specific spectral profiles of cinnabar and brown earth pigments. This analysis is part of a broader, ongoing integrated diagnostic campaign that also includes non-invasive XRF investigations. The damaged areas present on the painting (Fig. 6) were also examined using macro-photography, enabling precise identification of localized detachments (Damage Areas A, B, and C). Detailed images of these areas are shown in Fig. 7.

Fig. 6 Battle scene with damaged areas.

Area A (lower right corner): this loss exposes the underlying canvas weave, with associated detachment and flaking of the surrounding paint layer. The damage appears structural in nature, likely caused by mechanical impact or stress, with no evidence of previous restoration interventions. Area B (lower left): this circular loss reveals both the canvas and remnants of an old filling material. The difference in texture and coloration suggests a past restoration intervention that was not previously documented. This earlier repair shows signs of aging and surface cracking, indicating the potential need for retreatment. Area C (sky): linear loss affecting both the paint and ground layers, exposing the reddish preparatory layer beneath. The surrounding paint shows active deterioration, with visible lifting and flaking. The absence of filling or retouching suggests that no prior restoration work has been carried out in this area.

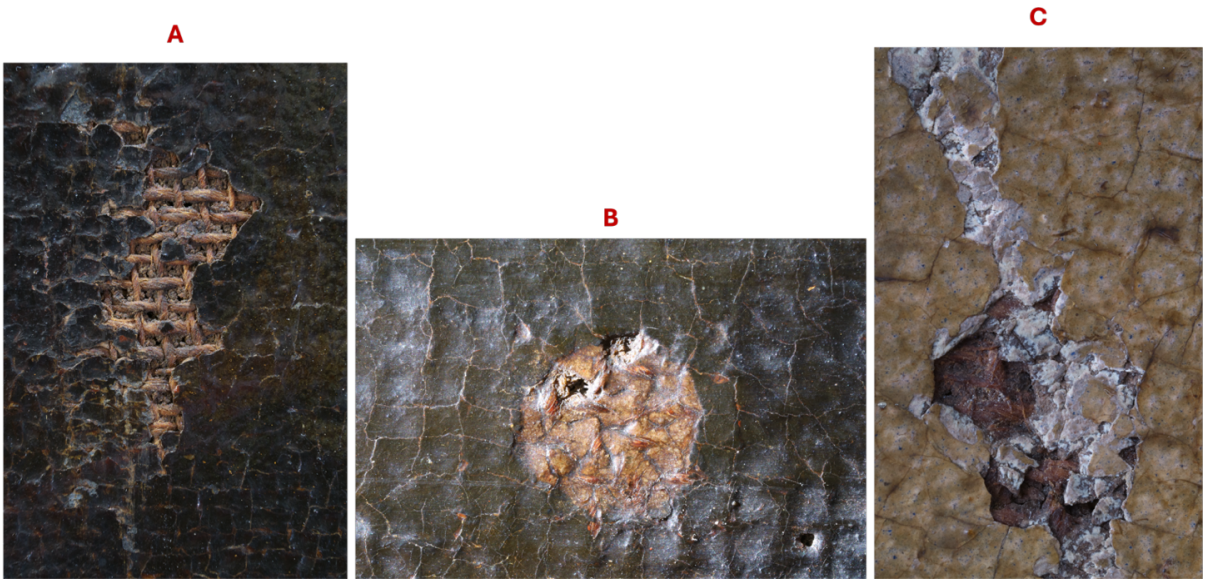

Fig. 7 Macrophotography details of damaged areas.

5. Conclusions

The integrated diagnostic approach employed in this study enabled the accurate identification of the pigments used in the analyzed painting, providing technical and scientific evidence consistent with the battle painting tradition dating between the 17th and early 18th century. The detection of historical pigments such as cinnabar, indigo, lead white, and possibly raw or burnt sienna attests to a refined and historically appropriate painting technique, aligned with the known practices of Jacques Courtois and his circle. However, the identification of Prussian blue, introduced only in the early 18th century, represents a critical diagnostic marker suggesting a post-1704 execution or intervention. This finding, along with the overall stylistic and technical features observed, supports the hypothesis that the painting may be attributed to a follower or workshop member of Courtois, rather than to the master himself. In conclusion, the scientific data corroborate the traditional stylistic attribution to the circle of Il Borgognone, while cautioning against a definitive attribution to the artist's own hand. The painting should be considered a high-quality workshop production or derivative work, executed between the late 17th and early18th century. Future investigations, including planned XRF analysis and direct comparative studies with authenticated works by Courtois and his contemporaries, will further clarify the dating and authorship of this remarkable painting.

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Colours of Early Cinema: The Case of Leopoldo Fregoli's Films (1897-1899) Through Diagnostic Investigation

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Abstract

Studies on colour in early cinema (the period from its emergence to its institutionalisation around 1915) have increased in the last years. At the very beginning of the film history the most common colour technique was the handmade painting of some selected parts of the image while other techniques as tinting and toning were most connected with the late standardization of the laboratory work. For many years film historians thought that early film, including those shot on Lumière brothers' stock, were also tinted on yellow. In 1990 Harold Brown wrote in his book *Physical Characteristics of Early Films as Aids to Identification* "Another feature of all the Lumière prints was that they have become discoloured to a deep amber shade; this should not be confused with amber tinting". Since then, film historians and archivists had thought that Lumière film stock was transparent and turn yellow over time. Indeed, the deterioration of the nitrate film follows a sequence of stages affecting both base and emulsion: support starts yellowing, then became brittle with distortion, image progressively fade and from the earliest stage is present the smell of nitric acid. The illusionist and quick-change artist Leopoldo Fregoli was among the early filmmakers who shot his films on Lumière stock. The surviving films of the Fregoli's production are preserved at the Cineteca Nazionale in Rome and object of a periodical inspection. This year the Cineteca Nazionale in collaboration with the ICR – Istituto Centrale per il Restauro and the University of Rome La Sapienza decided to analyse the film base of the Fregoli's collection to determine whether the films were originally coloured: they don't present the typical signs of the nitrate deteriorations, and the silver gelatine isn't fading, but at the same time film base is uniformly bright yellow. While diagnostic techniques such as Raman spectroscopy and X-ray elemental analysis have been employed in the literature to identify dyes and pigments in tinted and toned nitrate films, this study aims to use portable Attenuated Total Reflectance (ATR) Fourier Transform Infrared spectroscopy. This non-invasive technique allows for *in situ* film analysis, quantifying the cellulose nitrate degree of substitution to assess the state of conservation of the support (using an ATR specific calibration curve, based on studies conducted by Nunes *et al.* in 2020, assuming hydrolysis as the main mechanism of cellulose nitrate deterioration). In parallel, the presence of characteristic IR spectral peaks of specific dyes indicated in the historical recipes of Mariani (1916), Pathè (1926), and Eastman Kodak (1918) for yellow and orange dyes have been verified using FORS and Raman spectroscopy. These analyses represent the first step for further analyses aimed at a thorough investigation of Fregoli's films. The results of these analyses aim to answer the question of whether the yellow colouration observed in the Fregoli's positive prints is an original feature or a consequence of the support deterioration.

Keywords: early cinema; film restoration; diagnostic analysis; portable infrared spectroscopy.

Introduction

In 1953 the Cineteca Nazionale acquired 24 films (23 positives and one negative) made by the Italian illusionist and quick-change artist Leopoldo Fregoli between 1897 and 1899. The films were discovered by Mario Verdone in the possession of a private collector in Viareggio, where Fregoli had spent his final years. These films represent only a small portion of a much broader and richer body of

production. Film historian Adriano Aprà has attempted to reconstruct a complete filmography of Fregoli based on historical reviews and archival documents (Aprà, 2002). Fregoli's films are the oldest Italian productions preserved in the Cineteca Nazionale's archive and are regularly monitored for conservation *status*. In April 2025, a selection of these films was presented at the festival 'Custodi di sogni – I tesori della Cineteca Nazionale', prompting a renewed discussion around the issue of colour in early cinema.

For many years, film historians believed that early films, including those shot on Lumière stock, were tinted on yellow, as was common in silent cinema. Tinting was one of the main colouring techniques, but its introduction seems connected to the standardisation of film production in the 1910s. However, in the *Timeline of Historical Film Colors* (Flueckiger, 2012), the entry on tinting process identifies 1896 as the starting point of this practice and cites the Fregoli's film *Giochi di prestigio* (also known as *Fregoli prestigiatore*) as one of the earliest examples. This claim is based on a review by Fausto Montesanti, conservator of the Cineteca Nazionale, who wrote that *Fregoli prestigiatore* presents a light-yellow dye, typical for all films made using Lumière stock (Montesanti, 1954).

In 1990 Harold Brown wrote in his book *Physical Characteristics of Early Films as Aids to Identification* "Another feature of all the Lumière prints was that they have become discoloured to a deep amber shade; this should not be confused with amber tinting" (Brown, 1990). Since then, film historians and archivists have come to interpret the yellow hue of early prints not as intentional tinting, but as a sign of nitrate film stock deterioration. Indeed, the nitrate film deterioration follows a sequence of stages affecting both base and emulsion: support starts yellowing, then becomes brittle with distortion, image progressively fades and from the earliest stage is present the smell of nitric acid (FIAF, 2002).

Despite Brown's assertion, doubts persist and research on colour of early films continues. In 2011, Irela Núñez presented the restoration of *The Soldier's Courtship* (Robert William Paul, 1896) at the Collegium of Le Giornate del Cinema Muto film festival. The film (Figure 1, on the left) appears light yellow, as do many films from the early cinema period. However, following elemental analysis, no traces of dyes were found. Consequently, it was decided not to restore the colour, and the film was presented in black and white (Núñez, 2011). At the 2020 Domitor Conference, Jeanne Pommeau's presentation *Le mystère des couleurs des pellicules du Cinématographe Lumière* introduce an analysis of colour of Jan Kříženecký's films shot on Lumière stock (Figure 1, on the right). The initial hypothesis of this research, conducted with the University of Paris 8 Vincennes-Saint-Denis, was published in 2022 (Pommeau, 2022), but due to the ambiguity of the results, the study is ongoing employing new diagnostic techniques.

Fig. 1 – At left a frame from *Soldier's Courtship* (Robert William Paul, 1896) - Cineteca Nazionale, Rome and at right a frame from *Žofínská plovárna* (Jan Kříženecký,1898) - Národní filmový archiv, Prague.

To further complicate matters, in the latest and expanded edition of Harold Brown's manual, the author of the updated section on Lumière film stock, Eric Loné, writes: "For negatives, the coloration varies from green to dark yellow. In the case of dark yellow, the negative is more rigid, as it is thicker.

For positives, the colouring is most often yellow. In some cases, it is dark red. The reel is usually brittle. It isn't really appropriate to use the term 'tinting', which refers to an intentional treatment of the reel to achieve a specific effect. The term 'coloration' refers to the natural impact on the medium's original colour of the way it was manufactured" (Brown & Blot-Wellens, 2020). This "medium's original colour" depends on materials used to make the film base? The most recent inspection of the Fregoli's films has reignited all the questions around the colour of Lumière stock. The colours observed on the film elements appear vivid, intense, and uniform, quite unlike those typically associated with nitrate deterioration. Our research aims to determine whether any traces of colour are present in Fregoli's films using the spectroscopic analysis.

Fregoli's Film: Technical Characteristic, Conservation and Restoration

Fregoli's films were produced between 1897 and 1899. According to his autobiography (*Fregoli raccontato da Fregoli*, published in 1936) in 1897 Fregoli was on tour in Lyon at the Théâtre des Célestins where he claimed to have met the Lumière brothers. Fregoli was a great lover of photography and had begun to take an interest in cinema, so the Lumière brothers gave him a tour of their factory and allowed him to train there for a week. Upon returning to Rome with a model of Cinematograph, Fregoli began producing his own films (Aprà, 2002). However, despite Fregoli's account, there is no concrete evidence that he met the Lumière brothers. In fact, it appears that his first visit to Lyon occurred almost a decade later, in 1907, as reported by local newspapers. It is more probable that Fregoli first encountered the Cinematograph Lumière while participating in some of their productions, all filmed in Italy. It is likely that he received a camera and film stock from the Lumière cameramen during this shooting. What is certain is that in 1897 Fregoli began producing his own films, which featured rapid costume changes or behind-the-scenes tricks showcasing his transformations.

From a technical perspective, Fregoli's films are short works, each lasting between 40 and 45 seconds, shot on Lumière negative film stock and then printed in positives (see Figure 2). Both the negatives and positives are on 35mm nitrate film base with the characteristic round perforations (Brown, 1990). The image has an aspect ratio of 1.33:1.

Fig. 2 – At left a positive frame form *Al tavolo del ristorante* and at right *Sogno nuovo* - Cineteca Nazionale, Rome.

The films preserved at the Cineteca Nazionale are in good conditions: they present some scratches and some, due to their brittleness, tend to break when handled. Some films have areas where the emulsion (the photosensitive layer) and the film base (the support) are completely detached from one another. Yet there aren't the typical signs of nitrate decay. Only one film (Figure 4, right) shows signs of image fading.

This observation raises the central question of this research: were these films coloured? Due to ambiguity surrounding the yellow tinting, the only film that is certainly coloured is *Fregoli*

Prestigiatore (Figure 3). The colouring technique employed was the earliest used in cinema: the hand-painted colouring, descend from photographic retouching and magic lantern slides painting. The colours employed in this case were aniline-based and applied entirely by hand with a brush.

In 1995, all Fregoli's films were restored by the Cineteca Nazionale as part of the European Lumière Project. The restoration was carried out at the laboratory of the CNC – Centre National du Cinéma et de l'image animée (Surowiec, 1996). For this restoration, the decision was made to print the films in black and white and not to reproduce the yellow previously considered the result of an intentional tinting colourization (Montesanti, 1954). Brown's findings were taken into account. The only exception was *Fregoli prestigiatore*: for restoring the hand painting colours was used a Kodak colour film stock that also reproduced the yellow although ideally, for the sake of consistency with the other films, the background should have remained transparent.

Fig. 3 – Fregoli *prestigiatore*: at left the original and at right the restored version - Cineteca Nazionale, Rome.

The issue of the yellow colour remains unresolved. In figure 4 there are three examples of different colourations observed in the Fregoli's films: the first in the left is the most common (a bright yellow, almost orange), the second is a lighter yellow, the third suffer of image fading. This last sample corresponds more clearly to the typical nitrate deterioration, but the first two do not. It is difficult to attribute such vibrant and uniform colours, particularly in the first sample, to the film support decay. Even if these three samples represent different stages of degradation, the film stock of the first one appears too well preserved and with a colour too vivid (unlike the faded amber tones described by Brown) to be explained only by nitrate deterioration.

Fig. 4 – Three Fregoli's films with different colouration. The third in the right is the only one that shows signs of deterioration - Cineteca Nazionale, Rome.

Film Samples

As mentioned above, Fregoli's films are brittle and tend to break. This issue was already evident in 1995, when the films have been sent to the CNC for restoration. During that process, several fragments became detached from the reels and were collected and stored in their respective film cans. The samples analysed in this research are a selection of these small fragments, taken from both positives prints and the negative, and chosen according on their physical characteristics for providing examples from all types of material. Some fragments are complete with both the emulsion and the film base, while others consist of only one of these layers. Thanks to the separation of the emulsion from the support, it is clear that the yellow colour is characteristic only of the film base; furthermore, the two can be analysed separately.

Following the list of samples used in this study, including their inventory numbers from the Cineteca Nazionale, the number on the Fregoli's film catalogue and corresponding film titles.

Film positive samples: 13049 (Fregoli n. 1, *Fregoli retroscena*), 13050 (Fregoli n. 28, *Fregoli prestigiatore*), 13051 (Fregoli n. 13, *Pere cotte*), 13053 (Fregoli n. 23, *Al tavolo del ristorante*), 13057 (Fregoli n. 25, *Segreto per vestirsi con aiuto*), 13061 (Fregoli n. 11, *Fregoli e signora al ristorante*), 13062 (Fregoli n. 8, *Segreto per vestirsi*), 13065 (Fregoli n. 27, *Giochi di prestigio*), 13067 (Fregoli n. 3, *Fregoli in palcoscenico*), 13069 (Fregoli n. 26, *Fregoli retroscena 2*). Film negative sample: 13052 (Fregoli n. 7, *Sogno nuovo*).

We also used additional samples from other nitrate films as references for the dyes. Although these films were produced in the 1910s and present slightly different physical characteristics, they can still serve as useful references for colour identification, since their tinting processes are documented and the recipes for the dyes are known (Rossetto *et al.*, 2024).

Diagnostic methodologies

Fourier-Transform Infrared Spectroscopy – FTIR

FTIR analyses were performed using a portable Agilent 4300 FTIR spectrometer. Spectra were acquired in the range of 650–4000 cm^{-1} using an Attenuated Total Reflectance (ATR) measurement head equipped with a diamond crystal. Unlike the micro-FTIR technique, which requires micro-sampling of the material, this instrument enables the acquisition of IR spectra directly from motion picture films *in situ*, although the method is limited to obtaining molecular information from the surface layers only (either from the support side or the emulsion side), thus requiring at least two measurements per reel. This technique was employed to monitor the progression of the nitrate decay (i.e., a hydrolytic degradation process affecting cellulose nitrate), following the methodology described by Nunes *et al.* (2020). For each sample, two spectra per side were recorded (when both emulsion and nitrate support were present), and an average spectrum was calculated. Spectral analysis focused on the asymmetric stretching band of the nitro group ($\nu_a NO_2$ at 1636 cm^{-1}, selected as the probe peak, while excluding other nitrate vibration bands at 1274 and 827 cm^{-1}) and the stretching band of the cellulose backbone (νCOC at 1060 cm^{-1}, used as the reference peak). In fact, progression of cellulose nitrate decay is associated with a decrease in the absorbance of nitrate group bands (Nunes *et al.*, 2020). Peak intensity for $\nu_a NO_2$ and νCOC were determined using the peak height tool function in the OMNIC software, and the $\nu_a NO_2/\nu$COC ratio was then computed. The resulting values were interpreted using the FTIR-ATR calibration curve proposed by Nunes *et al.* (2020).

Fiber Optics Reflectance Spectroscopy – FORS

Visible Light Reflectance spectra were acquired using a BWTEK Exemplar LS fiber optic spectrophotometer. For each sample, three spectra were recorded (integration time: 2 s; scans: 5; integration step: 1 nm) and averaged. Apparent Absorbance (A′) was calculated using the log(1/R) transformation, where "R" denotes Reflectance, to complement the information obtained from the

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simple reflectance spectra. To minimize the effect of sample transparency, three spectra of the white paper used as the measurement substrate were recorded. The mean apparent absorption spectrum of paper was normalized to unity at its maximum and subtracted from each film sample spectrum as blank. The resulting spectra were subsequently normalized to unity at their respective maxima. Spectral attribution was carried out by comparison with reference data from the scientific literature (Montagner *et al.*, 2011; Rossetto *et al.*, 2024) and with four reference samples (from the 1910s) measured under the same conditions. This analysis aimed to identify possible dyes in the samples.

Raman and Surface-Enhanced Raman Scattering (SERS) Spectroscopies

For the Raman analyses, a Horiba Jobin-Yvon HR-Evolution spectrometer equipped with a microscope, a mapping stage and a 632.8 nm laser was used. For conventional Raman measurements, a preliminary collection of spectra was tempted, but the strong fluorescence background did not allow the acquisition, with the exception of two area on sample 13069. Set conditions for the spectra acquisition were: 100× objective magnification; acquisition time: 6 seconds; number of scans: 60; laser intensity 0.03 mW. The Ag-reduced colloid was prepared according to the protocol developed by Leopold and Lendl, 2003. Briefly, a solution of $AgNO_3$ 1×10^{-3} M in MilliQ Water was prepared. Separately, the same volumes of a solution of $NH_2OH \cdot HCl$ 6×10^{-2} M and a solution of NaOH 1×10^{-1} M were mixed together. Ten mL of $NH_2OH \cdot HCl$ solution was added to 100 mL of $AgNO_3$ solution under stirring, with direct formation of a colloid. The colloid was left under stirring for 20 min, and it was used after its production. 180 µL of Ag colloid was inserted in an Eppendorf tube and then 20 µL MilliQ water, where the nitrate sample has been left all over 24 hours, were added. 10 µL of this solution were put on a glass slide and they were left to dry. SERS spectra were acquired in correspondence of Ag nanoclusters on the glass slide. In order to evaluate eventual spectral interferences deriving from the colloid, spectra of the blank (180 µL of Ag colloid and 20 µL of MilliQ water) were also collected in the dried form. Set conditions for the SERS spectra acquisition were: acquisition time: 6 seconds; number of scans: 60; laser intensity 0.03 mW. Generally, at least three spectra for every typology of analysed sample were acquired. For the spectral band assignment and compound identification, experimental spectra were compared to databases and literature.

Colour recipes from manuals

A review of historical dye recipes reported in early motion picture film-colouring manuals allowed the identification of several yellow-orange dyes. These include: i) Orange G (Acid Orange 10), a synthetic mono-azo dye documented as one of the formulations for the "Cine Orange" tint (Agfa, 1925); ii) Cine Yellow or Niagara Fast Yellow, as well as Cine Orange or Orange A concentrated (Kodak, 1918), consisting of Chrysoidin 3R from National Aniline – Chemical Co. or Chrysoidin Y (Kodak, 1918); iii) a mixture of a yellow dye (Tartrazine) and a red dye (Eosin Y), both belonging to the pyrazolone family of dyes, i.e., molecules with a five-membered heterocyclic core containing two adjacent nitrogen atoms (Mariani, 1916); and iv) Auramine Yellow, Chrysoidin Orange or Orange d'Acridine (Pathé, 1926), with recommendations for the use of extra-concentrated Tartrazine (Société des Matières Colorantes de Saint-Denis) for yellow colouration, and Orangé Croccéine (Compagnie Nationale des Matières Colorantes) for amber colouration, whose shade (darker or lighter) depends on concentration.

Findings from diagnostic investigation

Fourier-Transform Infrared Spectroscopy – FTIR

Table reports the results of the ATR FTIR spectral interpretation for Fregoli's film samples. Considering the reference value of 2.26 (i.e., calibrated $\nu_a NO_2/\nu COC$) for virgin cellulose nitrate

(Nunes *et al.*, 2020), the values obtained for Fregoli's samples (i.e., ranging from 1.54 to 2.12) indicate that the material is not severely affected by nitrate decay. This is further supported by the observation by Nunes *et al.* (2020), who reported a value of 0.79 for a cellulose nitrate film reel exhibiting severe degradation, including cracking and embrittlement.

Table 1 – Indication of layer composition (emulsion, support) and calibrated $\nu_aNO_2/\nu COC$ ratio for each sample.

Sample n.	emulsion	support	ν_aNO_2	νCOC	$\nu_aNO_2/\nu COC$	Calibrated $\nu_aNO_2/\nu COC$
13049 pos.	yes	yes	0.24	0.16	1.47	1.92
13050 pos.	yes	yes	0.12	0.09	1.33	1.73
13051 pos.	no	yes	0.14	0.09	1.50	1.95
13052 neg.	no	yes	0.12	0.09	1.35	1.75
13053 pos.	yes	yes	0.18	0.11	1.59	2.08
13057 pos.	yes	yes	0.31	0.20	1.60	2.09
13061 pos.	yes	no	-	-	-	-
13062 pos.	yes	yes	0.21	0.14	1.47	1.91
13065 pos.	yes	yes	0.17	0.14	1.19	1.54 min.
13067 pos.	no	yes	0.20	0.13	1.50	1.96
13069 pos.	yes	yes	0.24	0.15	1.62	2.12 max.

Fiber Optics Reflectance Spectroscopy – FORS

In the case of FORS, the absorption spectra generally exhibit broad bands and therefore are not specific to a single compound. This limitation necessitated complementary SERS analysis; however, FORS provides valuable information (e.g., indications on the use of mixtures or pure compounds in colour formulation). Three distinct spectral patterns were identified (Figure 5), allowing the clustering of the analysed Fregoli's film samples:

- Category I - samples 13050, 13053, 13065 and 13067 exhibited a double absorption band centred at approximately 445 and 485 nm, partially resembling the behaviour of tinted reference samples 1 and 2 (with maxima at 450 and 500 nm). Such a profile could be consistent with Orange G (Crocein) dye (maximum at 480 nm, Rossetto *et al.*, 2024), resulting in a dark amber hue observed visually. Alternatively, a mixture of Tartrazine (maximum at 430 nm, yellow colour) and Eosin Y (maximum at 520 nm, red colour) could be considered; however, this appears less consistent with the obtained spectral profile, as the characteristic Eosin Y peak at 520 nm has not been observed.
- Category II - samples 13052, 13057, 13062 and 13069 displayed a single absorption maximum at 430 nm (slightly shifted to 440 nm for sample 13049). This absorption range matches that of Tartrazine or Auramine (maximum at 435 nm, Montagner *et al.*, 2011) and may also be compatible with Chrysoidin (maximum at 440 nm, but with a shoulder near 400 nm), producing the light-yellow appearance noted by visual inspection.
- Category III - sample 13051 presented a broadened single peak centred at 460 nm, partially resembling tinted reference samples 3 and 4 (with maximum at 450 nm). This spectral shape could result from dyes such as Chrysoidin or Acridine (maximum at 470 nm, but with a shoulder at 450 nm, Montagner *et al.*, 2011), yielding an observable pale amber colour.

The visual appearance of the samples (i.e., dark amber for Category I, light yellow for Category II, and pale amber for Category III) correlated well with the spectral profiles (Figure 5). Based on these

clusters, FORS guided the selection of representative samples for both Raman and SERS analysis: sample 13050 for Category I, sample 13069 for Category II, and sample 13051 for Category III.

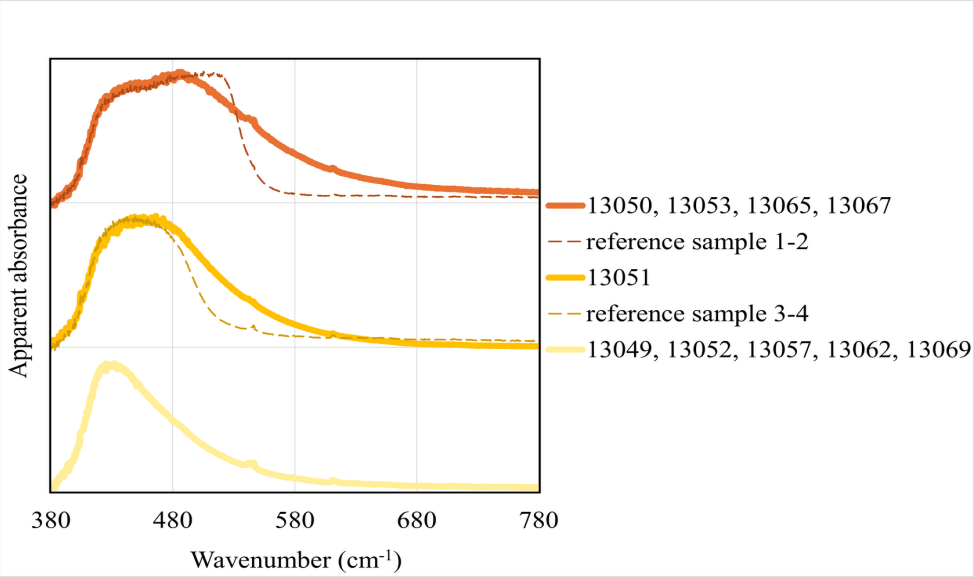

Fig. 5 – Top: Category I – average spectrum of samples 13050, 13053, 13065, and 13067 and comparison with reference samples 1 and 2; Bottom: Category II – average spectrum of samples 13049, 13052, 13057, 13062, and 13069; Middle: Category III – spectrum of sample 13051 and comparison with reference samples 3 and 4.

Raman and SERS spectroscopies

Raman analyses were performed on three samples selected among the different clusters identified by FORS analysis, i.e., 13050, 13051 and 13069. However, it was not possible to acquire clear spectra for the different samples, because in every case the fluorescence background was so strong, which did not allow to identify any useful vibrational feature. Only in the case of the 13069 sample, two spectra were acquired, showing signals attributable to the polymer matrix: a broad band at 859 cm^{-1} could be attributed to the stretching of N-O bond, while the intense signal at 1286 cm^{-1} is indicative of the symmetric stretching of NO_2 group (Povolotckaia *et al.*, 2025). These data confirm the presence of cellulose nitrate.

The preliminary SERS analyses performed on the three samples did not show main signals attributable to dyes: the different spectra show a pattern with a strong similarity to the silver colloid one (the most evident signals at 680, 1004, 1029, 1056 cm^{-1} are also present in the spectrum of the blank), so no clear identification it is possible. Probably, the simple extraction of the dye in water was not successful. However, some minor signals could support some hypotheses. For instance, in the case of the 13050 sample, two bands at 1380 and 1601 cm^{-1} could be attributed to N=N stretching and to aromatic C-C stretching, respectively: these assignations are in agreement with the presence of a simple mono-azo dye, such as Orange G hypothesized on the base of FORS spectra (Rossetto *et al.*, 2024; Si *et al.*, 2012; Vannucci *et al.*, 2021; Zhang *et al.*, 2020). However, for a clear identification of the molecular structures, it was considered necessary to improve the analytical methodology, so further measurements are in progress, in order to obtain the specific characterization of the eventual dyes.

Conclusion

Considering the good overall condition of the cellulose nitrate (as confirmed by visual homogeneity and ATR FTIR analyses) and the FORS spectra, which present defined spectral patterns, with a

general matching with dye spectra reported in the literature, the presence of dyes is strongly suggested. In particular, the FORS results support the presence of a dye belonging to one of three possible families (i - Orange G or Crocein, ii - Tartrazine or Auramine, iii - Chrysoidin or Acridine). An interesting aspect to highlight, anyway, it is represented by the impossibility of acquiring SERS spectra on the water extract from the samples, which did not show any visible variation in colour. The observed resistance of the dye to aqueous extraction may be indicative of a dyeing process most likely occurred at the time of film support production (possibly pre-dyed rather than subsequently tinted). Usually, tinted colorization could be easily removed with water and in some case with isopropyl alcohol used during manual cleaning. At this point, the molecular structure identification is required, in order to both confirm the presence of dyes and elucidate technological processes used for the manufacturing of Leopoldo Fregoli's films. From this point of view, the application of different SERS approaches is foreseen, along with further methodologies providing further structural information.

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Color and Environment

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Color Beyond Vision: Exploring Synesthetic Interactions in Built Environments

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Abstract

Anchored in interdisciplinary studies from cognitive science, phenomenology, and sensory design, this paper investigates color as a multisensory catalyst in spatial design. Through a mixed-methods approach—combining literature review with non-interventionist field observation in retail built environments—it examines how color interacts with scent and texture to shape affective atmospheres. Two case studies—a futuristic boutique in Seoul and a classical perfumery in Milan—demonstrate how the color red evokes contrasting sensory and emotional responses. Findings highlight both the potential and the challenges of applying multisensory color strategies in experiential environments. By reframing color as an embodied, affective phenomenon, the paper offers new pathways for crafting more immersive, inclusive, and emotionally resonant experiences.

Keywords: multisensory design, synesthetic perception, color psychology, built environments, spatial experience.

Introduction

In contemporary design practice, color has evolved from a primarily visual and symbolic element to a multisensory agent capable of influencing perception, emotion, and behavior. Studies in neuroscience, cognitive and environmental psychology demonstrate that sensory perception is inherently cross-modal and embodied, involving dynamic integration across modalities such as smell, touch, hearing, and taste (Mehrabian and Russell, 1974; Spence, 2011). Within this point of view, color can operate as a trigger for complex sensory associations, aligning with the phenomenon of synesthesia, typically defined as a condition in which stimulation in one sensory modality involuntarily evokes experiences in another. Although often considered rare and neurological in origin, research shows that synesthetic correspondences also occur in the general population and can be strategically leveraged in design contexts to enrich experience and engagement (Haverkamp, 2013). In built environments—especially in affective, commercial, or exhibition spaces—color holds potential as a catalyst for evoking textures, temperatures, sounds, and scents (Malnar and Vodvarka, 2004). These understandings have significantly influenced design disciplines, fostering experiential approaches in the conception of objects, materials, and spaces (Ferrara, 2020).

Despite the growing discourse on multisensory design, the role of color in cross-modal perception remains underexplored in both theory and practice. This article investigates the following research question: "*How can color function as a multisensory agent in the design of built environments, and what mechanisms support its capacity to trigger, modulate, or amplify sensory experiences beyond vision?*". Combining critical literature review, analysis of key experimental studies and non-interventional field observation in selected retail environments, this study focus on how specific chromatic strategies—particularly the use of red—contribute to sensory and emotional experience. By reframing color as an active agent in multisensory storytelling, the study highlights its role in shaping spatial atmospheres and embodied experiences. It also examines the relevance of semantic anchoring—verbal associations that connect color to affective or sensory attributes—as a tool to support design coherence and perceptual resonance. Ultimately, the research supports a shift toward sensory-integrated approaches in spatial and brand experience design.

Methodology

This paper adopts a qualitative exploratory mixed-methods approach, combining: (a) Comprehensive state-of-the-art literature review; (b) Analysis of foundational experiments exploring cross-sensory effects; (c) Field non-interventionist observations at selected retail spaces. The literature review draws from diverse fields, including design, neuroscience, cognitive and environmental psychology. This interdisciplinary approach informs an understanding of how color influences psychological processes such as mood, perception, memory, and behavior, and how these insights can improve sensory integration in spatial design. To support this, the study includes a scanning of experiments that consider cross-sensory aspects. The selection and examination of these studies were guided by two criteria: (1) Sensory modalities involved (such as color in interaction with smell, touch, or sound); and (2) Key findings or contributions relevant to understanding the affective and perceptual impact of chromatic stimuli.

This structured review contributed to identifying recurring mechanisms of sensory interaction and assisted the interpretation of spatial observations that complement the theoretical insights. The non-interventionist observations were conducted in two contrasting retail environments Case Studies — Born to Stand Out (Seoul), a futuristic boutique with synthetic scents, and The Merchant of Venice (Milan), a classical perfumery characterized by natural fragrances. These locations were selected for their distinct sensory and chromatic strategies, particularly the use of red to shape immersive brand atmospheres. Rooted in ethnographic and phenomenological traditions, the observations focused on embodied sensory experience without interference or participant interaction. Although this approach limits generalizability due to the absence of controlled experimentation or biometric data, it prioritizes rich contextual understanding of how color can activate multisensory and emotional responses in curated retail spaces. The methodology is particularly suited to experiential retail and brand storytelling, but further research is needed to validate it in areas like healthcare and education.

Literature Review

Color perception has traditionally been framed within a visual paradigm that privileges sight over other sensory modalities, particularly in architecture and spatial design. This ocularcentric orientation tends to reduce the multisensory complexity of spatial experience, overlooking how perception emerges from embodied and integrated sensory input. Phenomenological thinkers such as Merleau-Ponty (1962) offer a foundational critique of this bias, suggesting that perception is not a passive visual act, but an active, corporeal engagement with the world. In this embodied view, space is simultaneously seen, smelled, touched, tasted and heard—its meaning constructed through dynamic sensorimotor interaction (Zatore and Belin, 2001). Interdisciplinary research supports a shift from this visual-centric approach toward multisensory approaches. Cognitive neuroscience and environmental psychology have demonstrated the interdependence of sensory systems, especially through crossmodal interactions—phenomena where stimuli in one sensory modality influence perception in another. Studies by Spence (2011, 2015) reveal that visual information modulates tactile, olfactory, and even gustatory responses, underscoring the multisensory nature of human experience. Within this expanded approach, color emerges not as an isolated chromatic value but as a perceptual trigger capable of activating a wide range of embodied and emotional associations.

Beyond sensory processing, color functions as a semiotic system within the broader context of cultural and environmental meaning-making. Semioticians such as Barthes (1977) and Eco (1976) have emphasized how color operates as a code, carrying denotative and connotative significance that is culturally and contextually contingent. For instance, red may evoke urgency, passion, or danger depending on the setting and cultural background. This symbolic dimension interacts dynamically

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with perceptual processes, meaning that color influences not only how spaces are seen but also how they are interpreted and emotionally experienced (Farina, 1990). In design theory, this expanded understanding has inspired new methodologies that actively integrate multisensory cues. Malnar and Vodvarka (2004) advocate for sensory design strategies prioritizing emotional resonance, memory formation, and immersive affective engagement beyond mere surface aesthetics. Color, when combined with olfactory, tactile, and acoustic stimuli, becomes a powerful agent in crafting immersive environments, particularly in retail contexts where emotional engagement is central to brand communication. This sensorial language of design, as argued by Lupton and Lipps (2018), moves beyond purely visual stylization toward na inclusive and holistic sensory articulation.

Empirical research elucidates these multisensory interactions further. Crossmodal correspondences—learned or innate associations between sensory features—demonstrate how color systematically links to other sensory modalities. For example, warm colors like red are commonly associated with sweet tastes (Spence, 2011, 2015), while certain hues correspond consistently with specific odors (Gilbert *et al*., 1996; Zellner, 2013). Although synesthesia—characterized by involuntary, consistent cross-sensory experiences—is neurologically rare, it offers a conceptual model inspiring design practices that blur sensory boundaries (Haverkamp, 2013). At the neural level, studies by Gottfried and Dolan (2003) and Osterbauer *et al*. (2005) reveal that color can influence olfactory perception via convergent activation in the orbitofrontal cortex. These neural mechanisms underpin observed behavioral effects in consumer settings, where congruent color–odor pairings enhance product recognition and hedonic ratings (Zellner *et al*., 1991; 2013), whereas incongruent pairings tend to disrupt perception and attenuate affective response (Stevenson & Oaten, 2008; Tamura *et al*., 2018).

In spatial environments, such multisensory integration extends to atmospheric perception. Color primes olfactory expectations and modulates emotional encoding of scents (Dubose *et al*., 1980), strategies increasingly employed in retail and wellness spaces to communicate affective qualities. Additionally, color influences cognitive processes including attention, memory, and decision-making. For instance, warm hues are linked to arousal and tenacity (Spence, 2011, 2015), while cool tones facilitate calm and introspection. These effects are culturally mediated, reinforcing the importance of contextualized design approaches (Heller, 2004; Barbara *et al*., 2021). Other studies have further extended the understanding of crossmodal color associations beyond olfaction and taste to include tactile perception. Spence (2011, 2015) demonstrated that individuals consistently associate tactile textures with specific chromatic qualities—smooth textures were linked to lighter or cooler colors such as white and blue, while rough textures evoked darker or earthier tones such as brown or burgundy. These findings point to stable cognitive mappings between tactile and visual domains, which can be strategically leveraged in material and spatial design (Haverkamp, 2013; Lupton and Lipps, 2018).

Crossmodal associations are shaped by culture. Levitan *et al*. (2014) found that while color–odor pairings were consistent within each cultural group, they varied significantly across cultures—likely influenced by factors such as diet, symbolism, and sensory traditions. These findings highlight the need for culturally attuned design strategies that consider local sensory meanings. Taken together, these theoretical, cultural, and empirical insights establish color as a dynamic sensory interface—one that communicates meaning through both direct perceptual input and associative semiotic layering. Recognizing color's multisensory and semiotic roles enables designers to craft spaces that are immersive, emotionally engaging, and culturally resonant. To advance this understanding, Table 1 presents the result of an analytical review obtained from key crossmodal experiments involving color, categorized by the sensory modalities involved and principal findings related to color as a

multisensory agente. This synthesis lays the foundation for investigations into how multisensory color integration can enhance the psychological and emotional experience within built environments.

Author(s)	***Sensory Modalities***	***Key Findings / Contributions***
Baron-Cohen et al. (1987)	Vision, Audition	Case study of lexical–color synesthesia showing involuntary and consistent color associations with spoken words.
Dubose et al. (1980)	Vision, Olfaction	Showed that color primes olfactory expectations and modulates emotional encoding of scents.
Gilbert et al. (1996)	Vision, Olfaction	Identified systematic color–odor correspondences in non-synesthetes; suggests shared or learned crossmodal mappings.
Gottfried & Dolan (2003)	Vision, Olfaction	Demonstrated convergent activation in orbitofrontal cortex for visual and olfactory stimuli, revealing neural basis for crossmodal perception.
Levitan et al. (2014)	Vision, Olfaction	Revealed consistent and divergent odor–color correspondences across cultures.
Osterbauer et al. (2005)	Vision , Olfaction	Found chromatic stimuli modulate odor perception in the brain.
Spence (2011, 2015)	Vision, Taste, Touch	Tested associations between color and taste and demonstrated consistent correspondences between tactile textures and colors: smooth textures were associated with light or cool colors, while rough textures corresponded to dark or earthy tones.
Stevenson & Oaten (2008)	Vision, Olfaction	Demonstrated that appropriate color cues improve odor discrimination.
Tamura et al. (2018)	Vision, Olfaction	Showed citrus-like smells enhance memory for orange color stimuli.
Zellner & Whitten (1999)	Vision, Olfaction	Showed that color intensity affects odor identification and pleasantness.
Zellner (2013)	Vision, Olfaction, Taste	Synthesized research on color-odor interactions, proposed integrative models.
Zellner et al. *(1991)*	Vision, Olfaction	Found influence of color on odor identification and liking ratings.

Table 1 – Summary of Key Studies on Cross-Modal Interactions Involving Color

Case Studies

This section presents a comparative analysis of two distinct retail environments where the color red functions as a pivotal sensory catalyst, shaping emotional, cognitive, and spatial experiences. Both cases exemplify the concept of color beyond vision, illustrating how chromatic elements interact multisensorially with form, texture, and scent to produce immersive brand narratives. The *Born to Stand Out* (Figure 1) boutique in Seoul embodies a radical, futuristic aesthetic that challenges traditional retail design conventions. Here, red is deployed not merely as a visual stimulus but as a dynamic multisensory agent that evokes urgency, movement, and noise. The space's design features organic, fluid forms juxtaposed with satin-like surfaces, rustic stone, mirrors, and carpet textures, producing a tactile complexity that complements the chromatic vibrancy (Malnar and Vodvarka, 2004; Lupton and Lipps, 2018). The predominance of satin finishes—distinct from gloss or matte—introduces subtle light diffusion, intensifying the perceptual richness of red while avoiding overt glare (Heller, 2004; Spence, 2011, 2015).

Olfactory elements further reinforce this dystopian atmosphere. The brand's synthetic fragrances, characterized by atypical and chemically derived notes, resonate with the unsettling, synthetic nature of the environment, enhancing the sensory dissonance and conceptual urgency (Gottfried & Dolan, 2003; Barbara *et al*., 2021). This sensory orchestration aligns with crossmodal correspondences, whereby color and scent mutually amplify emotional impact (Osterbauer *et al*., 2005; Spence, 2011). Through this multisensory layering, red in this space transcends a purely aesthetic role to become a

catalyst for embodied experience, eliciting visceral responses of alertness and dynamism that mirror the brand's avant-garde identity. Contrasting sharply with Born to Stand Out, *The Merchant of Venice* (Figure 1) perfumery invokes tradition and refinement. Here, red assumes a more classic and restrained character, supporting an environment steeped in historical references and sensory sophistication. The interior design features polished lacquered surfaces and classic furniture, which reflect light to create a luminous environment where red hues signify luxury and elegance (Farina, 1990; Leder *et al*., 2004; Heller, 2004). The chromatic use is more controlled and semantic, functioning as a signifier of heritage and craftsmanship. Natural and often floral fragrances permeate the space, corresponding to the rich olfactory heritage of the brand.

Fig. 1 – Born to Stand Out (left) and The Merchant of Venice (right). Source: Author.

This olfactory authenticity synergizes with the visual richness of red, enhancing the sensory narrative with notes of warmth and exclusivity. This synergy between red and scent, combined with tactile cues from glossy materials, constructs a multisensory environment where red catalyzes associations of refinement, elegance, and timelessness. It demonstrates the capacity of color to anchor semantic meanings that extend beyond visual perception, consistent with synesthetic design principles (Haverkamp, 2013; Spence, 2011, 2015). These case studies illustrate the polysemic nature of red, demonstrating its versatility as a sensory catalyst that can evoke divergent affective states depending on contextual variables such as materiality, scent, and spatial form. By integrating these sensory modalities, designers can harness the power of red not only to attract attention but to orchestrate embodied experiences that resonate emotionally and cognitively with users.

Discussion

The comparative analysis of *Born to Stand Out* and *The Merchant of Venice* underscores the strategic role of red as a multisensory catalyst in retail spaces, contributing to distinct experiential outcomes through its interaction with other sensory modalities. This reinforces the theoretical proposition that color operates beyond mere visual perception, functioning within complex sensory ecologies that shape consumer experience (Spence, 2011; Lupton and Lipps, 2018). The findings align with models of cross-modal correspondences which describe how sensory modalities such as vision, olfaction, and

touch co-activate and mutually influence perception and affective states (Osterbauer *et al*., 2005; Zellner, 2013). In both retail contexts, the deployment of red is not isolated but entwined with scent profiles and tactile materials, enabling emotional modulation—urgency and dynamism in one case, elegance and sophistication in the other. This supports Leder *et al*. (2004) model of aesthetic appreciation, which posits that sensory stimuli evoke cognitive and emotional responses through an interplay of perceptual and contextual factors.

By engaging multiple senses coherently, retail environments can foster deep embodied experiences that enhance brand meaning and consumer engagement (Merleau-Ponty, 1962; Mehrabian and Russell, 1974; Malnar and Vodvarka, 2004). The contrasting sensory narratives exemplify the context-dependent nature of color perception and meaning-making. As Farina (1990) and Heller (2004) emphasize, cultural and environmental contexts influence color semantics, shaping the psychological and emotional connotations that color invokes. The use of synthetic vs. natural fragrances in tandem with chromatic cues highlights the potential for sensory congruence or dissonance to reinforce or disrupt brand identity narratives (Gottfried & Dolan, 2003; Tamura *et al*., 2018). This dynamic interaction exemplifies the concept of sensory anchoring, whereby non-visual cues stabilize and elaborate the emotional and cognitive effects elicited by color (Leder, 2004; Heller, 2004; Spence, 2011). From a design practice perspective, the cases highlight both opportunities and constraints in implementing multisensory color strategies. The Born to Stand Out store illustrates how red's association with urgency can activate consumer attention and stimulate movement within space, beneficial in contexts requiring high engagement (Farina, 1990; Spence, 2011; Barbara *et al*., 2021).

Conversely, The Merchant of Venice illustrates how red can convey heritage and exclusivity, aligning with luxury retail goals where sensory harmony and emotional subtlety are central (Leder *et al*., 2004; Heller, 2004). Despite its potential, multisensory color integration presents several design challenges. Managing olfactory dispersion in open spaces, ensuring sensory congruence across materials and scents, and addressing individual or cultural variability in color-scent associations require careful, context-specific calibration (Stevenson & Oaten, 2008). Designers must also consider environmental constraints, ventilation systems, and cross-cultural interpretations to avoid misalignment in sensory messaging (Levitan *et al*., 2014). In sum, this study advances an approach to understanding color as a multisensory, experiential catalyst in retail design, showing how strategic integration of chromatic, olfactory, and tactile elements can shape distinctive brand atmospheres and consumer experiences. This aligns with sensory design paradigms that prioritize embodied, cross-modal engagement over visual dominance (Lupton and Lipps, 2018).

Conclusion

This study explored the role of red color as a multisensory catalyst within retail environments, emphasizing its capacity to transcend visual perception and orchestrate a coherent sensory experience through the integration of olfactory, tactile, and spatial elements. The analysis of the *Born to Stand Out* and *The Merchant of Venice* stores demonstrated how chromatic design, in concert with complementary sensory stimuli, can evoke distinct emotional and cognitive responses, shaping consumer engagement and brand identity. The findings contribute to the growing body of literature that challenges the traditional primacy of vision in design, advocating for embodied, multisensory approaches that recognize the complexity of human perception. They underscore the importance of contextual and cultural factors in shaping the semantic and affective qualities of color. From a practical standpoint, the study illustrates that retail designers can leverage multisensory color strategies to create differentiated, immersive experiences that align with brand narratives, whether oriented towards dynamism and futurism or tradition and sophistication. From these insights, the following pathways offer strategic guidance for integrating color as a multisensory design element to craft immersive, inclusive, and emotionally resonant environments (Table 2).

Pathway	***Description***	***Benefit***
Multisensory Integration	Combine color with texture, scent, flavor and sound	Deeper emotional engagement
Contextual Adaptation	Adjust color tone and finish by cultural context	Cultural relevance
Dynamic Surfaces	Use lighting and material finishes to alter color	Stimulates interest
Inclusive Design	Pair color with other sensory cues for accessibility	Broader audience engagement
Olfactory-Color Pairing	Match scents with color tones	Stronger sensory narrative
Semantic Anchoring	Use color to anchor brand meaning	Brand identity reinforcement
Phygital Experience	Blend physical and digital color interactions	Interactive engagement

Table 2 – Summary of Key Studies on Cross-Modal Interactions Involving Color

The study also underscores challenges related to sensory coherence and individual variability, which demand greater methodological rigor and design sensitivity. Future research should adopt empirical and experimental approaches to quantify the multisensory interactions of color across varied retail contexts, utilizing perceptual studies, sensory mapping, longitudinal behavior analysis and cross-cultural comparisons to test and expand the proposed approach. Emerging neuroscientific and biometric tools—such as eye tracking, neuroimaging, and psychophysiological measures—offer promising methods for objectively evaluating embodied sensory experience and enhancing multisensory design principles. Finally, the evolution of digital and phygital retail environments introduces new complexities and opportunities for color-based sensory design, requiring interdisciplinary collaboration across design, technology, and cognitive science to advance sensory branding strategies in omnichannel retailing. These insights are particularly relevant to experiential retail, exhibition design, and brand environments where emotional engagement is a design priority. As such, they inform both academic discourse and practical strategies for creating immersive, inclusive, and affectively resonant spaces.

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The Impact of Colour Schemes on Perception and Behavioural Intentions in a Coffee Shop Context

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Abstract

Coffee shops have become one of the most frequently visited social spaces after homes and workplaces. Numerous coffee shops, with varying concepts and qualities, operate in Türkiye and worldwide. Undoubtedly, the primary goal of these places is to attract customers, leave a positive impression, and build loyalty through the quality of the service they offer and the holistic impact of their space design. In this context, regardless of the product offered, visual atmospheric elements such as light, colour, and materials are among the critical design elements that shape the first impression of a space and directly influence user preferences. However, how these elements influence customers' behavioural intentions towards the space and the coffee it offers remain insufficiently understood. Corporations and service providers increasingly rely on spatial design strategies to shape customer experience. In hospitality environments like coffee shops, the visual atmosphere strongly affects affective responses, spatial impressions, and behavioural tendencies. This study investigates which colour schemes are more pleasant, attractive, and catchy, and how different interior colour schemes (monochromatic, analogous, and complementary) influence customers' behavioural intentions to visit a coffee shop. The study participants were presented with generic coffee shop scenarios (12 images), each designed using a distinct colour composition (monochromatic, analogous, and complementary contrast), based on four pure colours selected from the NCS colour system. Data were collected through a structured online questionnaire, completed by 168 participants. Results show that monochromatic colour schemes are perceived as more pleasant, attractive, and catchy than analogous and complementary schemes. Furthermore, significant correlations were found between perceived visual qualities of the colour schemes and customers' behavioural intentions, suggesting that interior colour composition plays a meaningful role in shaping consumer responses in coffee shop environments.

Keywords: Colour, visual perception, coffee shop interiors, behavioural intentions, environmental psychology.

Introduction

Colour is a fundamental component of interior design that significantly influences how people perceive and interpret spatial environments. As a powerful visual stimulus appealing to vision—the most dominant human sense—it plays a critical role in shaping emotional tone, ambiance, and spatial impressions (Wang et al., 2022; Adams, 2013). Interior colour schemes, defined by the harmonious arrangement of hues perceived together, directly affect user perception and behaviour within built environments (Bilal et al., 2021; Cha et al., 2020). Designers employ colour not only to enhance visual appeal and stylistic coherence but also to support practical functions and elicit specific emotional responses, such as calmness or stimulation (Olguntürk, 2015; Evans & McCoy, 1998).

Harmonious colour schemes—based on similarity or contrast—are often constructed using analogous or monochromatic hues, or through alignment in saturation and lightness levels (Billmeyer & Saltzman, 1981). When selected and applied thoughtfully, such combinations can evoke distinct

psychological responses (Olguntürk, 2015), thereby contributing to both the aesthetic and functional quality of interior spaces. This is particularly important in environments like coffee shops, which function as both social "third places" and commercial settings (Haktanir & Gullu, 2023). In such contexts, colour becomes a key design element shaping emotional responses, influencing how pleasurable a space feels—an affective factor strongly linked to behavioural intentions (Ryu & Jang, 2008; Motoki et al., 2021).

Colour schemes are essential in shaping interior spaces' visual and emotional qualities (Meerwein et al., 2007; Ulucay, 2018a). Among these, monochromatic colour schemes consist of various tints, shades, and tones derived from a single hue, offering a sense of visual harmony and cohesion (Elliot et al., 2015). Analogous colour schemes include hues adjacent to each other within a quarter segment of the colour wheel, resulting in a unified and calming effect (Cha et al., 2020). In contrast, complementary colours are composed of two hues that sit directly opposite each other on the colour wheel, generating strong visual contrast and vibrancy (Meerwein et al., 2007). More complex arrangements, like double complementary (tetradic) schemes, involve two complementary colour pairs, providing richness and balanced tension (Meerwein et al., 2007). Triadic colour schemes feature three hues evenly spaced around the wheel, forming an equilateral triangle and creating a balanced yet lively composition (Olguntürk, 2015). Similarly, tetradic colour schemes comprise four colours arranged as complementary pairs, offering diversity while maintaining harmony (Hu et al., 2012). Understanding these structured relationships between hues is essential for intentional and effective colour use in design, as they influence aesthetic outcomes and user perceptual and emotional responses (Odabaşıoğlu, 2020; Ulucay, 2018b).

Beyond its aesthetic value, colour also holds the power to transform user experience by stimulating mental and physiological reactions (Kaszuba & Sobczyńska, 2019). It can enhance well-being when integrated with care and balance. While bold and saturated hues may energize and attract, subdued and desaturated tones are more likely to calm and soothe, making colour an adaptable tool that can be tailored to diverse user needs (Ulusoy et al., 2020). However, if used excessively or without consideration of harmony, colour may overwhelm or disrupt the user experience (Shehata, 2000). Therefore, designers must strike a careful balance between expressive richness and functional clarity to ensure colour enhances rather than detracts from the quality of interior environments (Park & Guerin, 2002; Kaszuba & Sobczyńska, 2019).

According to the literature review, images of real-world environments have been used in most previous studies on the interior ambiance of coffee shops (Song et al., 2019; Susanti et. al., 2021; Wang & Song, 2025). Although these studies have provided insightful information, significant methodological constraints exist due to their reliance on physically accessible, already-existing coffee shops. Confounding aspects beyond the interior's visual and spatial characteristics, such as coffee's flavour, previous service experiences, background noise, or familiarity with the area, could affect participants' assessments. These restrictions present difficulties for studies that seek to identify and thoroughly evaluate how particular visual components affect behaviour and perception.

In response to this gap, the present study focuses exclusively on the visual impact of colour schemes in coffee shop interiors by controlling other environmental variables. It systematically examines how customers perceive colour schemes (monochromatic, analogous, and complementary) through digitally rendered images—three fundamental harmony strategies in colour theory. Four pure hues selected from the NCS colour system form the basis of these compositions, ensuring visual consistency and experimental control. Participants rated the environments on dimensions such as pleasantness, attractiveness, and catchiness, as well as their behavioural intentions, including the likelihood of revisiting or recommending the space.

This study aims to deepen our knowledge of how specific colour compositions shape users' emotional evaluations and spatial preferences by isolating the colour scheme as a key environmental variable. It emphasizes perceptual responses and examines behavioural trends, such as the intention to engage

with the space. Ultimately, the findings are expected to offer evidence-based insights into the role of colour in shaping commercial interior experiences. These results hold significant implications for stakeholders involved in creating customer-oriented public environments. The study contributes to developing more effective, emotionally resonant, visually appealing commercial spaces by revealing how different colour harmony strategies influence user engagement.

Methodology

This study adopts a quantitative research method and is implemented through an online survey administered via Google Forms. The structured questionnaire is composed of three primary sections: (1) the Ishihara Colour Blindness Test, (2) Demographic Information, and (3) the Evaluation of Visual Impressions and Behavioural Intentions. The Ethics Committee of Bilkent University has approved the study.

At the beginning of the questionnaire, participants review an information sheet detailing the study's purpose, question types, and potential risks or benefits. Informed consent is obtained via a confirmation item. The first section includes 12 Ishihara plates to screen for colour vision deficiencies; participants with incorrect responses are excluded from analysis. The second section gathers demographic data (age, gender, and education). The third and final part of the study focused on the Evaluation of Visual Impressions and Behavioural Intentions.

The researchers designed a generic coffee shop interior with a minimal and stylistically neutral spatial composition to ensure experimental control and internal validity. Material and lighting conditions were constant across all scenarios. Using 3ds Max, twelve digitally rendered visuals were created, each representing the same interior with only the colour schemes manipulated—monochromatic, analogous, and split-complementary (four visuals per scheme) (See Fig-2). Colour selection was guided by the Natural Colour System (NCS) to ensure precision and consistency. Four pure hues—S 1050-Y (yellow), S 1050-R (red), S 1050-B (blue), and S 1050-G (green)—were selected with uniform blackness and chromaticness levels; for purple, S 1040-R50B was used due to NCS limitations (See Fig-1). The colour schemes were constructed according to harmony principles: monochromatic visuals featured tonal variations within a single hue; analogous schemes combined each base hue with two adjacent hues on the NCS Colour Circle; and split-complementary schemes used colours flanking the direct complement to balance harmony and contrast. Colour was applied only to visually prominent surfaces (e.g., walls, floors, seating), while other components were rendered in white (S 1000-N) or chrome to minimize distraction. Participants viewed each visual and responded to seven items using a five-point Likert scale (1 = Strongly Disagree to 5 = Strongly Agree), evaluating their perception of the environment and intention to visit. Perceptions of colour—pleasantness, attractiveness, and catchiness—were measured using items adapted from Mondol et al. (2021). Behavioural intentions were assessed through four additional items from the same source, capturing expectation fulfilment and likelihood of future engagement with the space (e.g., "The overall colour impression of this coffee shop fulfils my expectations"; "I intend to purchase products from this coffee shop").

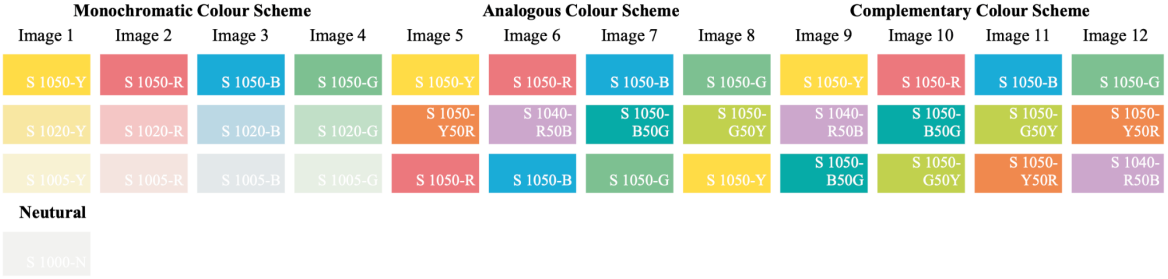

Fig. 1 - Selected Colour Schemes for Generic Coffee Shop

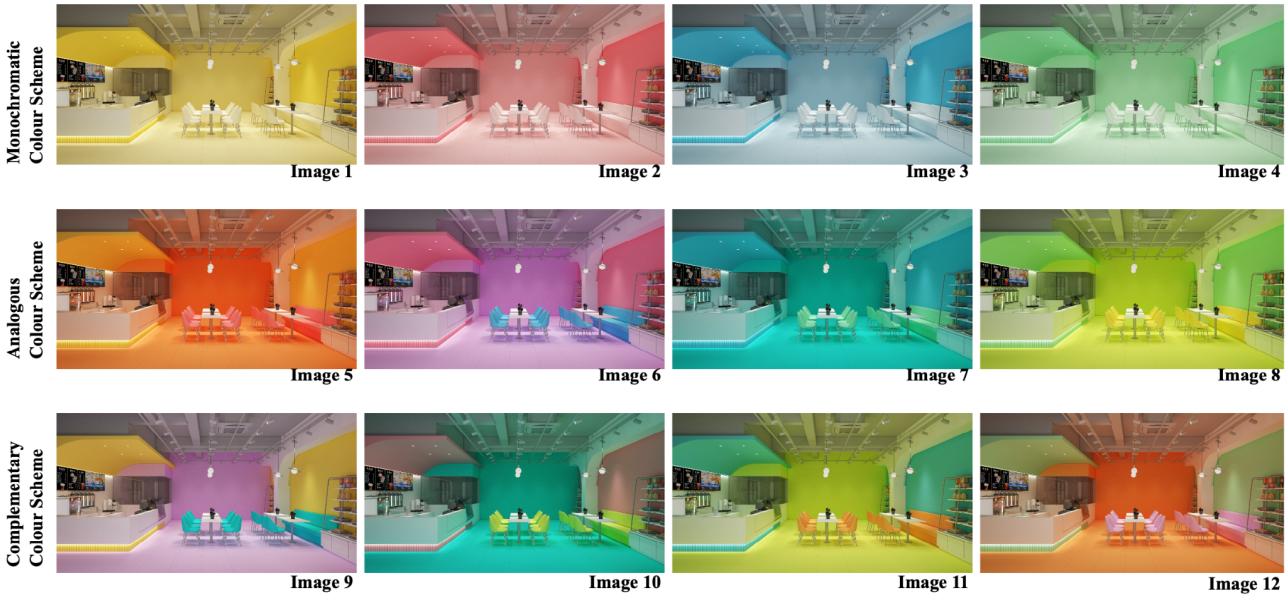

Fig. 2 - Visualization of Coffee Shop with Selected Colours

Participants were selected through a random sampling method to enhance the generalizability of the findings. The target population consisted of adults aged between 18 and 65 years. The sole inclusion criterion was passing the Ishihara Colour Blindness Test. Participants who failed to meet this criterion were excluded from the dataset and from the statistical analyses to ensure the validity of colour-related evaluations. This study investigated how different colour schemes—specifically monochromatic, analogous, and complementary palettes—in coffee shop environments influenced customers' perceptions and behavioural intentions, focusing on their motivation to revisit the space. Based on this aim, the research questions of the study were as follows:

R.Q.1: Does the pleasantness perception significantly differ across different colour schemes (monochromatic, analogous, and complementary)?
R.Q.2: Does the perception of attractiveness significantly differ across different colour schemes?
R.Q.3: Does the perception of catchiness significantly differ across different colour schemes?
R.Q.4: Do customers' behavioural intentions significantly differ across different colour schemes?
R.Q.5: Is there a significant correlation between perceived pleasantness and intention to purchase from the coffee shop?
R.Q.6: Is there a significant correlation between perceived attractiveness and the intention to transact with the coffee shop in the future?
R.Q.7: Is there a significant correlation between perceived catchiness and the intention to transact with the coffee shop in the future?

Results and Analysis

The collected data was analysed by using IBM Statistical Package for the Social Sciences 27 (SPSS). A total of 174 participants responded to the questionnaire. However, six of them did not pass the Ishihara colour blindness test; therefore, statistical analyses were conducted using the data from the remaining 168 participants who successfully completed the test. To understand the demographic profile of the participants, information about their gender, age, and educational background was collected. The results showed that 61,9% of the participants were female (n=104) and 38,1% were male (n=64). An examination of the age distribution revealed that 13,7% of the participants were between 18–24, 24,4% were aged 25–34, 29,8% fell within the 35–44 age range, 19,6% were between 45–54, and 12,5% were aged 55–64. Regarding education level, 1,2% of the participants had

completed primary school, 2,4% secondary school, 17,3% high school, 51,8% held a bachelor's degree, 16,7% a master's degree, and 10,7% had earned a doctoral degree. This demographic variety improves the generalizability of the study findings. Before moving on with the statistical analyses, the internal consistency of the scale was assessed using Cronbach's Alpha coefficient. The overall reliability of the questionnaire was found to be very high, with a Cronbach's Alpha value of .984, indicating excellent internal consistency among the items.

Before proceeding to the statistical analyses, a descriptive analysis was conducted by examining the mean scores of the visuals. Individual visuals and colour scheme groups averaged the participants' responses. In terms of pleasantness, the colour schemes were ranked as monochromatic (M=2.70, SD=,89), complementary (M=2.38, SD=,93), and analogous (M=2.31, SD=,91). For attractiveness, the ranking was similar: monochromatic (M=2.68, SD =,89), complementary (M=2.46, SD=1,01), and analogous (M=2.39, SD=,95). Regarding catchiness, the order differed slightly, with monochromatic (M=3.08, SD=1,06) ranking first, followed by analogous (M=2.75, SD=1,12) and complementary (M=2.71, SD =1,09).

When examined at the image level, the highest pleasantness mean was found for Image 1 in the monochromatic scheme (M=2.91, SD=1,16), Image 5 in the analogous scheme (M=2.63, SD=1,30), and Image 12 in the complementary scheme (M=2.56, SD=1,24). The same order was observed for attractiveness, with Image 1 (M=2.85, SD=1,18) in the monochromatic scheme, Image 5 (M=2.70, SD=1,28) in the analogous scheme, and Image 12 (M=2.60, SD=1,28) in the complementary scheme. For catchiness, the ranking again remained consistent, with the highest means recorded for Image 1 in the monochromatic scheme (M=3.36, SD =1,28), Image 5 in the analogous scheme (M=3.05, SD=1,37), and Image 12 in the complementary scheme (M=2.84, SD=1,28).

The first three research questions investigated whether perceptions of pleasantness, attractiveness, and catchiness differed across the three colour schemes. Participants rated each visual on items measuring these attributes, and repeated measures ANOVAs were conducted.

For *pleasantness*, Mauchly's Test indicated a violation of sphericity ($W = .903$, $\chi^2(2) = 16.91$, $p < .001$), and the Greenhouse–Geisser correction was applied ($\varepsilon = .912$). Results showed a significant main effect of the colour scheme, $F(1.823, 304.52) = 21.48$, $p < .001$, $\eta^2p = .114$. Monochromatic schemes were rated significantly higher than analogous ($MD = .390$, $p < .001$) and complementary ($MD = .311$, $p < .001$) schemes, while analogous and complementary did not differ significantly ($MD = –.079$, $p = .429$).

For *attractiveness*, sphericity was violated ($W = .860$, $\chi^2(2) = 24.96$, $p < .001$) and corrected ($\varepsilon = .878$). A significant main effect emerged, $F(1.755, 293.09) = 11.22$, $p < .001$, $\eta^2p = .063$. Monochromatic schemes were rated more attractive than both analogous ($MD = .295$, $p < .001$) and complementary ($MD = .223$, $p = .009$), with no significant difference between analogous and complementary ($MD = .071$, $p = .540$). For *catchiness*, sphericity was again violated ($W = .896$, $\chi^2(2) = 18.14$, $p < .001$), with correction applied ($\varepsilon = .906$). A significant effect was found, $F(1.812, 302.67) = 22.80$, $p < .001$, $\eta^2p = .120$. Monochromatic schemes were rated catchier than both analogous ($MD = .338$, $p < .001$) and complementary ($MD = .375$, $p < .001$), with no difference between analogous and complementary ($MD = .037$, $p = 1.000$). For *behavioural intentions* (RQ4), sphericity was violated ($W = .857$, $\chi^2(2) = 25.58$, $p < .001$) and corrected ($\varepsilon = .875$). A significant effect was found, $F(1.750, 292.26) = 19.16$, $p < .001$, $\eta^2p = .103$. Monochromatic schemes delivered higher behavioural intention scores than both analogous ($MD = .344$, $p < .001$) and complementary ($MD = .237$, $p = .001$), and there is no statistically significant difference between analogous and complementary (MD

= –.107, p = .073). Monochromatic schemes were consistently rated highest in pleasantness, attractiveness, catchiness, and behavioural intentions, while analogous and complementary schemes showed no significant differences.

To check if there is a correlation between perceived pleasantness and behavioural intentions of customers in the coffee shops (RQ5), it can be seen that across all three colour schemes, behavioural intention showed a strong positive correlation with perceived pleasantness, indicating that higher pleasantness ratings were consistently associated with stronger intentions to engage with the coffee shop. Specifically, the correlation was r = .910 (p < .001) for the monochromatic scheme, r = .942 (p < .001) for the analogous scheme, and r = .946 (p < .001) for the complementary scheme.Again to find if there is a correlation between perceived attractiveness and behavioural intentions of customers in the coffee shops (RQ6), across all three colour schemes, behavioural intention was found to have a strong positive correlation with perceived attractiveness, suggesting that higher attractiveness ratings are consistently associated with stronger intentions to engage with the coffee shop. Specifically, the correlation was r = .905 (p < .001) for the monochromatic scheme, r = .921 (p < .001) for the analogous scheme, and r = .908 (p < .001) for the complementary scheme. The similarity of these coefficients indicates that the strength of the relationship between attractiveness and behavioural intention remains stable regardless of the applied colour scheme.

Finally, when we checked for a correlation between perceived catchiness and customers' behavioural intentions in the coffee shops (RQ7), the analysis revealed strong, positive, statistically significant correlations between behavioural intention and catchiness across all three colour schemes. For the monochromatic colour scheme, behavioural intention demonstrated a strong positive correlation with catchiness (r = .764, p < .001). Similarly, the analogous colour scheme had a strong, positive, and statistically significant association between the two variables (r = .751, p < .001). The complementary colour scheme also exhibited a strong positive correlation, with behavioural intention and catchiness closely linked (r = .822, p < .001). These findings indicate that, regardless of the colour scheme, higher perceptions of catchiness are associated with stronger intentions to visit, purchase, or recommend the coffee shop.

Conclusion

This study provides empirical evidence that different colour schemes significantly shape customers' perceptual and behavioural responses within coffee shop environments. Monochromatic colour schemes consistently exceeded analogous and complementary schemes across all dimensions—pleasantness, attractiveness, and catchiness. This may be interpreted as presenting a clear preference for visual harmony and simplicity in such settings. Moreover, strong and statistically significant correlations between perceived visual qualities and behavioural intentions highlight the importance of colour composition as a strategic design tool for influencing customer engagement. The results indicate that monochromatic schemes enhance affective evaluations of the space and positively influence customers' behavioural intentions to fulfil expectations, visit, and purchase the coffee shop. In contrast, analogous and complementary schemes produced similar results, indicating that while colour contrast may contribute to visual interest, it does not necessarily translate into stronger behavioural intentions.

This study measured participants' colour preferences and behavioural intentions in a generic coffee shop with 12 images of colour schemes created using colours selected from the NCS Colour System. Colours were chosen with medium chromaticity and the lowest shared black value for each pure colour. However, the study has several limitations. First, spaces can be designed with countless different colour combinations. Furthermore, all variables except colour were held constant in this

study; however, light, sound, and materials can also influence behavioural intention. Including these factors in a controlled manner in future studies will produce more comprehensive results. From a practical perspective, this study offers valuable colour-related insights for stakeholders in the hospitality sector, demonstrating that monochromatic schemes can effectively enhance positive emotional responses and customer engagement. These findings provide a solid design reference for aligning interior colour strategies with desired customer experiences. Further studies could build on this work by incorporating other atmospheric variables—such as lighting, material, and scent—to explore their combined impact on consumer behaviour across different cultural contexts.

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The Color as an element of space definition: Schlemmer's moving architectures

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Within the historic German art and design school of the Bauhaus, the use of color was far from being regarded as a merely aesthetic or formal aspect, it became a significant element representing the creative revolution that the school introduced to 20th-century architecture and art. Through studies on the theory and expressive potential of color by key figures such as Johannes Itten, Wassily Kandinsky and Paul Klee, the use of color was elevated to an essential element of every artistic project. It was conceived as a dynamic and expressive force capable of permeating all disciplines practiced within the school's workshops.
Among the most fascinating explorations of color was that conducted by Oskar Schlemmer within his role as director of the Bauhaus Theatre Laboratory. His approach, inspired by Gestalt theories, was embedded in a theoretical framework that considered color as a fundamental element in the perception and representation of space. For Schlemmer, the geometry of the *theatrical scene* became a site of experimentation where theories on spatial construction were explored through t*he use of color and the form* of *moving architectures* of costumes (or *figurines*) designed for defining dancers' movements. Schlemmer used color as a dynamic tool to explore the *spatial geometries* created by the bodies of dancers, transformed into mechanical-like forms, constrained by the rigid volumes of the moving architectures, contributed to creating stereometric scenarios and opening new horizons for perceiving stage space. The juxtaposition of various tones, the use of unconventional colors and strong contrasts, particularly in the *Triadic Ballet*, enabled, through choreographed movements and the exaggerated geometries of the costume-machines, the manipulation of perceived distance, proximity and depth within the space. New *illusionary geometries* were generated without altering the actual physical structures of the stage environment.
Schlemmer's studies continue to inspire experimental research today, reinforcing the role of color as a language capable of redefining and transcending the geometric space of the stage, contributing to new interpretations of space itself. His vision anticipated contemporary practices in immersive and virtual scenography. Schlemmer's experimentation remains highly relevant today, influencing interactive performance, digital theater, and the visual arts. His work established the foundations for new immersive approaches that merge body, space and technology into multisensory experiences.

Keywords: color, movement, body, spatial geometries, perception, costumes

Introduction

The Bauhaus school, founded in 1919 in Weimar, stands as one of the most radical and influential interdisciplinary experiments of the twentieth century. Conceived as a unified project, the Bauhaus reimagined art, architecture, design, dance, music and theatre as components of a single *Gesamtkunstwer*, a total work of art, according to the vision of the founder Walter Gropius. The German school functioned as a true experimental laboratory, capable of anticipating many of the theoretical and design paradigms that would shape modernity.
Oskar Schlemmer the director of the Bauhaus Theatre Laboratory Bauhaus, developed an innovative scenic language that broke with mimetic and narrative traditions. His stage was conceived as an abstract and rational space, governed by geometric and perceptual principles. Color was central to this vision, functioning as a fundamental element in the perception and representation of space. Schlemmer's experimentation was grounded in the interaction between form, body and environment. The costume - conceived as a form of *moving architecture* - was a medium device between body and space, transforming the dancer into a mechanical and geometric figure. Color, applied to both

costumes and stage design, operated as an active tool for shaping three-dimensional spatial configurations and producing illusory environments.
This paper aims to investigate the role of color in Oskar Schlemmer's theatrical work, focusing particularly on the design of his *moving architectures*. Color will be interpreted here as both a spatial and design tool, capable of activating complex perceptual configurations. This conceptual approach anticipates, in embryonic form, many contemporary practices in digital scenography, immersive installations and interactive environments, where color continues to function as an active and transformative medium of space.

Schlemmer and Colour Theory at the Bauhaus

The *Programm des Staatlichen Bauhauses in Weimar*, the Bauhaus manifesto, outlined the primary aim of the new institution: to overcome disciplinary separations between applied arts, visual arts, and architecture and radically reform the relationship between art and society. The German school thus emerged as a laboratory of experimentation, whose methodological, pedagogical and formal innovations anticipated theoretical and design programmes in architectural planning and aesthetic studies of the relationships between body and space.
Within this context of radical experimentation, colour - far from being regarded merely as an aesthetic quality or formal attribute - was investigated as a tool capable of activating perceptual, emotional, and cognitive processes, becoming one of the pillars of creative renewal not only in teaching but also in architecture and art throughout the century. The research on colour theory and its expressive possibilities undertaken by prominent Bauhaus figures such as Johannes Itten, Wassily Kandinsky and Paul Klee helped to redefine colour not only as a means of expression but also as a design instrument endowed with its own linguistic and constructive autonomy. In this context, colour was elevated to an indispensable component of both the school's pedagogical activities and design works, becoming a central element of every artistic project.
Each of these artists and theorists developed a distinct and coherent vision of colour capable of profoundly interacting with perception, space and emotion, playing a fundamental role in the creation of a modern and multidisciplinary aesthetic. In particular, the studies of Itten, Kandinsky, and Klee had a significant impact on the performative experiments of Oskar Schlemmer, who - thanks also to the stimulating dialogue with these three masters and their singular approaches - was able to reach an innovative theoretical synthesis, whose principles involve body, movement, form and space.
Johannes Itten, the first director of the *Vorkurs* (the Bauhaus's preparatory course), developed a colour theory of dual origin, scientific and emotional, interweaving sensory perception, emotion, and spirituality. In his teaching, he combined visual perception exercises, chromatic experiments and meditative practices helping students to "understand and feel" the colour, intellectually but also to feel it intuitively and physically. Itten's theory of colour, inherently tied to subjective interpretation, were enriched, under the influence of theosophy and Eastern doctrines, by connections to individual psychological types and the seasons. His introduction of the *twelve-hue colour circle*, structured according to the laws of harmony and contrast, and his classification of the seven fundamental colour contrasts - especially hue, light-dark, warm-cool and complementary contrasts - aimed to stimulate and deepen students' perceptual sensitivity (Itten, 2001). In Schlemmer's work, Itten's influence can be traced in the chromatic construction of costumes and stage designs, there the contrast between primary and complementary colours serves not only as visual function but also contributes to defining the psychological and gestural qualities of the dancers on stage.
Unlike Itten, Kandinsky developed a colour theory founded on a synesthetic and spiritual conception of art. Colour was considered an inner force, capable of evoking deep emotions and resonating with specific forms: each colour possessed its own "sound," which could be associated with a particular geometric form, thus generating a universal emotional-visual language. Blue, deemed spiritual and introspective, aligned with the circle; red, stable, warm and grounded, with the square; yellow, sharp, energetic and aggressive, with the triangle (Kandinsky, 2005). From the moment Kandinsky arrived

at the Bauhaus, Schlemmer established a dynamic and fruitful dialogue with him. Although Schlemmer did not fully adhere to Kandinsky's symbolic and spiritualist theories of colour and form, his influence profoundly shaped Schlemmer own experimentation, notably in the *Bauhaus-tänze*, true interdisciplinary experiments in conceptual dances and in his celebrated *Triadic Ballet*.

From Paul Klee, finally, Schlemmer developed a distinctive synthesis combining intuition, scientific analysis and pedagogical spirit. Klee's colour theory, developed also through studies of music and nature, distanced itself from both Itten's rigid classification and Kandinsky's abstract spirituality, taking on a more abstract and dynamic atmosphere. In his Bauhaus teachings, Klee conceived colour as living material capable of suggesting processes, transformations, and internal tensions within the work. His reflections were expressed through diagrams, notes and drawings aiming to rende r visible the laws of movement and form in pictorial space, often comparing chromatic relationships to musical intervals. His famous statement, «Art does not reproduce the visible, but makes visible»(Klee, 1959), applies equally to colour, viewed as an evocative force surpassing mere sensory description, and to Schlemmer's interpretation of it. Though more rationalist in his approach to form construction, Schlemmer shared with Klee the idea that colour could function as an evocative and symbolic element, capable of leading the viewer into an imaginary and abstract dimension, something he actualised in his productions, where colour, detached from naturalism, participates actively in the formal construction of the scene.

Oskar Schlemmer's work can be considered as a personal and innovative synthesis of the three main conceptions of colour developed within the Bauhaus. Interwoven, these approaches converged into a new guiding principle: colour conceived as an autonomous entity endowed with generative power, able to structure perception and interact with space. The attention to chromatic balance and contrast inherited from Itten, Kandinsky's synesthetic and spiritual vision of colour as rhythm and expressive force and Klee's ability to use colour as an instrument of abstraction and poetry all supported Schlemmer in creating productions designed as interdisciplinary experiences in which colour played a vital role.

Through these continuous theoretical confronts and elaboration, Schlemmer developed a genuine scenic code. In his productions, colour became a structural element of visual rhythm, theatrical time, and dramaturgical meaning. The use of colour to highlight the choreographic movements of performers, present in most of his stagings, reflected the belief that colour can generate geometries linked to internal sensations and serve as a vehicle for invisible yet perceptible forces.

Color and Space in Schlemmer: *The Triadic Ballet*

During his directorship of the *Bauhaus Bühne*, Oskar Schlemmer was able to fully articulate and develop the core principles of his artistic research. The stage workshop, the *Bühnenwerkstatt*, evolved from a mere space for representation into a true experimental laboratory, where a Gestalt approach was adopted to redefine the very concept of the stage in relation to performance and the role of the spectator.

With a background as both painter and choreographer, the multifaceted German artist seized the opportunity offered by the direction of the Bauhaus theatre to explore the relationships between the human body, movement and the geometry of the space in which it is immersed. He affirmed: «Color and form reveal their elementary values within the constructive manipulation of architectonic space. Here they constitute both object and receptacle, that which is to be filled and fulfilled by Man, the living organism»(Schlemmer, Moholy-Nagy, Molnár, 1971). The primary object of Schlemmer's research, infact, was the human body, which he examined in relation to specific elements including movement, space, form, light and color. The genre he selected for this exploration was theballet, although his experimental approach constituted a clear rupture with classical theatrical conventions. Despite being seen as a declining form, in contrast to eurythmics and the cult of strength and beauty, ballet placed emphasis on «the brightly colored masquerade once so popular with people; theatrical costume dance; and also ballet, to be born in a new form. For human beings will always love bright

games, disguises, masquerades, dissimulation, artificiality, as they will always love any festive, eye-catching, colrful reflection of life»(Schlemmer, 1972). The ballet gave «possibilities for expression and articulation which an opera or a play could not offer in such purity ; theatrical dance (…) is free of constrains» (Schlemmer,1972).

Aiming at an abstraction of representation, increasingly free from narrative constraints and at a conceptual unity of the stage production, closer to Walter Gropius's idea of a total work of art,Schlemmer, scientifically influenced by Dalcroze's theories on eutonics (the overcoming of bodily arrhythmia, that is, the lack of coordination between brain impulses and their reception by the muscular system, achieving an eutonic state of balance between bodily and mental impulses) and by Diaghilev's Ballets Russes (which he critiqued for the lack of fusion among all scenic elements), began his initial experiments with choreographic compositions consisting of three dances, in which the dancers wore costume-armor several years before joining the Bauhaus (Russo, 2019).

He created the most iconic avant-garde ballet of the era, the *Triadic Ballett* (Fig.1), which indeed reached its "definitive" form after a long period of trials and experiments. The 1926 production included music partly composed by Paul Hindemith, whose work Schlemmer believed "adds a spiritual dimension to everything he touches." This music resembled that of a music box and contributed to giving the dancers the appearance of dolls. This parallel between the costumes and the mathematical mechanics of the body created a spectrum ranging from the "cheerful grotesque to full pathos" (Schlemmer, 1972).

In the prologue, an actor read Kleist's *Über das Marionettentheater*, thereby formalizing Schlemmer's aesthetic exploration of the mechanical figure and the anthropomorphic double through the dancer's body. The influences of Kleist's puppet, considered superior to any human dancer, Craig's super-marionette, a metaphysical substitute for the actor and Hoffmann's automaton - all stemming from a shared inquiry into the mechanical nature and reproducibility of human gesture - respond to what Schlemmer would call «the longing for the liberation of man from his constraints, and for the exaltation of his full autonomy of movement, beyond natural measure» (Fiorillo, 1994). The human figure, along with the organic and inorganic nature of man as analyzed by Schlemmer, found its synthesis within the abstract space of the tridimentional scene, in the movement of the dancer who, as a human being, was considered "the measure of all things" and who, precisely within the constructed architecture of the stage, revealed his system of measurement and the possibility of creating both real and unreal spaces.

The title *Triadic Ballet*, associated to the mathematics principles of the number three, refers to the concept of the triad, conceived as an organizing principle that constantly explores and plays with combinations of one, two, and three: three acts, three characters per act - a female dancer and two male dancers - who performed twelve dances with eighteen different costumes, in a constant balance between dance, costume, and music. The other triads Schlemmer referred to were composed of form, color, and space; the spatial dimensions: height, depth, and width; the basic geometric shapes: sphere, cube, pyramid; and the primary colors: red, blue, yellow (Schlemmer, 1972).

Color was an essential element in defining the stage space: each of the three acts was characterized by a distinct chromatic atmosphere, supporting a choreographic style with a specific representational character. The stage in which the dancers performed the various choreographies was conceived by Schlemmer as entirely empty, devoid of scenography or props. Nevertheless, the use of solid color backgrounds for each act strongly distinguished the setting, creating the appropriate emotional tone for each section. The first act features a yellow backdrop, whose tone is playful and burlesque, light and humorous, dominated by pastel shades and agile, almost caricatural movements. The choreographies are marked by lively gestures and circular or rotational motions of the limbs. The second act introduces more saturated and vibrant tones, accompanied by geometric and mechanical movements that evoke a Futurist dimension. This act is characterized by a pink background, described as festive and solemn. The black backdrop of the third act frames the scene as a mystical and

imaginative fantasy, where the dancers'spiral movements follow a slowed and ritualistic choreography, producing a meditative and solemn effect. The creation of the "metaphysical" space of the *Triadic ballet*, marked by the alternation of One, Two, and Three in form, color and movement, is further reinforced by the planar geometry of the stage surface and, above all, by the stereometry of the moving bodies. This generates a sense of spatial dimensionality, resulting from the execution of movements such as the straight line, diagonal, circle and ellipsemperformed by the dancers wearing their costume-armors, made from different materials and fabrics. (Russo, 2019)

The creative medium between mathematics and the metaphysical scene of the triad was, in fact, the human body, whose metamorphosis «is made possible by the costume, by disguise. The costume and the mask emphasize the identity of the body or alter it; they express its nature or deliberately obscure it; they underline its conformity to organic or mechanical laws or negate such conformity»(Gropius, W., 1987). Schlemmer designed costumes akin to armor that transformed the dancers' bodies into true *moving architectures* In his essay *Mensch und Kunstfigur*, Schlemmer writes: «form and color must merge into a figure that, moving in space, transforms it into visual and sonic rhythm»(Schlemmer, 1972), underlining the fundamental importance of color in the creation of new scenic spaces. The costumes, genuinely plastic in nature, were characterized by large volumes and a strongly geometric construction - cylinders, prismatic structures, spheres, cones - that created a striking interaction between the body and the stage space. Forged three-dimensionally like armor, they were equipped with padding, prosthetics, and rigid protective coverings, made from various materials such as glass, plaster, celluloid, rubber and different types of metals, in order to exploit their diverse acoustic properties as well.

The dancers' stage movements were profoundly conditioned by the costumes, which intentionally limited certain bodily motions while "activating" others, generating a new abstract grammar of gesture. Transformed into true "scenic machines", the dancers explored innovative figurative possibilities, moving toward a form of plastic movement determined by the heavy and coloured costumes. The audience, immersed in this visual and auditory environment, did not witness a linear narrative but rather experienced a synesthetic event. The dancers, through the chromatic geometries of the moving costumes, contributed to creating the illusion of an architectural transformation of the stage space. Even without physically altering the structure or dimensions of the stage, the spectator experienced a dynamic and mutable perception of space. Depending on the color and type of costume worn, visual effects were generated that constructed illusory spaces- a continuous perceptual game evoking the idea of *Schau-Spiel* - literally "vision-play," a true feast for the eyes.

The ensemble created by these moving architectures gave rise to what Schlemmer defined as "stereometric scenarios": illusory spatial configurations produced through the interaction of the costumes' colored geometric forms and their associated choreographic movements. Although these scenarios did not materially transform the stage, they significantly altered the viewer's perception—its visual depth, spatial proportions, and formal articulation of scenic space. In summary, Schlemmer used these mobile architectures to create sequences of spaces perceived as distinct, shaped by gestures and choreographies that the costumes and,inparticular the color combined to the shapes, rendered "visible." In this context, color actively defines the scenic space, becoming a tool for the perceptual manipulation of spatial dimensions and assuming the role of a perceptual and compositional code, fundamental to the reading of theatrical space.

*Schlemmer's costume typification merges geometry with color to transform the human body. He theorized four types of costumes: the moving architecture where the head, torso, arms and legs are stylized into cubical forms; the marionette represents rigid, controlled motion; the technical organism emphasizes mechanical movement; while dematerialization explores the body's gradual dissolution in space. Each concept reflects specific gestures and spatial relationships, shaping a complex interplay of form and movement. (*Schlemmer, Moholy-Nagy, Molnár, 1971). He uses the example of a human figure dressed simply in a white leotard to illustrate how the dancer's body, in this neutral

state, can be transformed by the addition of coloured elements such as a red sock on a white pants. These accessories, though small, alter the figure's initial balance, creating a unilateral modification that decisively influences both the internal and external arrangement of the body, and therefore its movement. The effect of color is not just aesthetic but profoundly impacts the perception of the body in space and its dynamic behavior. These impacs are evident in the *Triadic ballet* interesting figurines movements (Fig.2). The bifrontal *Disco* costume which moved according to the direction of the disc they were cut from. The red and blue discs stood out against the black background, visually creating a colored line during the movement on stage, extending along two opposite directions and signaling both the geometries of the plane and the mask. In the *Abstract* costume, which Schlemmer himself had worn, the performer appears as though immobilized at the center, with one leg fixed in a rigid structure, allowing only certain movements. This creates the impression that the performer is divided in half, both human and puppet at the same time. The dancer's body is transformed into a *moving architecture*, generating spatial illusions that challenge the traditional perception of the stage. The costumes not only limit or amplify specific movements, but also contribute to the construction of a synesthetic experience, in which geometry, color and choreography merge into a visual interplay that directly engages the spectator's perception.

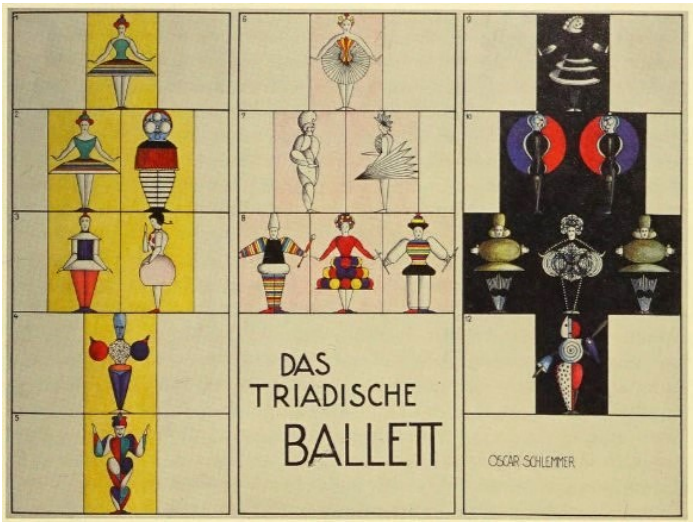

Fig.1

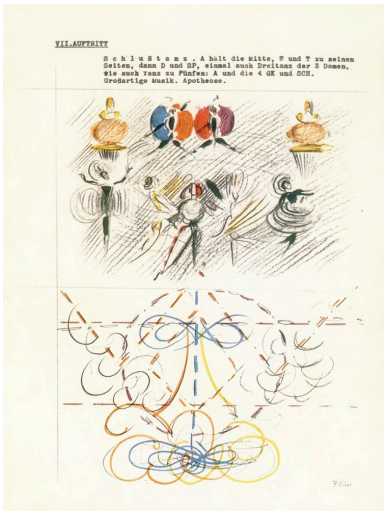

Fig.2

Fig. 1 - Costume Designs for the *Triadic Ballet.*
Fig.2 - Movement patterns of the dancers for the *Triadic Ballet*.

The Relevance of Schlemmer's Thought: From the Bauhaus to the Contemporary Stage

The conceptual legacy of Oskar Schlemmer, particularly his view of color as a means to define performative space, extends well beyond the confines of the Bauhaus. *Triadic Ballet* became the most widely performed avant-garde artistic dance of the modernist stage, leaving a lasting impact on the performing and visual arts of the mid-to-late 20th century and the 21st century. Schlemmer's research, grounded in the synthesis of body, form, movemen, and color, through mathematical dance and *moving architecture*, laid the foundation for further experimentation in visual and multimedia theatre, digital scenography and immersive installations.

Post-WWII figures such as Josef Svoboda and Robert Wilson reinterpreted, albeit through different languages, several core principles of Schlemmer's theatrical approach. The Czech architect and scenographer, in the 1960s and 1970s, developed a dynamic scenographic concept based on the decomposition of space using light and chromatic projections. As Jarka Burian states, this approach «might be called colored space or spatial color; in either case, the emphasis is on a three-dimensional use of color, primarily through the use of expressive surface forms and impressionistic projections» (Burian, 1974). Svoboda's kinetic scenographies, like those in *Laterna Magika*, evoke a direct

continuity with Schlemmer's stereometric scenarios, where space is constructed through moving bodies and chromatic geometries. Similarly, Robert Wilson created a form of visual theatre where light, color and slow-motion movement combine to produce environments of high perceptual density. His assertion that «color is visual architecture. It is a way to build time in space» (Wilson, 2010) resonates deeply with the Bauhaus view of color as a structural element of the stage. Kathy O'Donnell points out that «Schlemmer's work anticipates the dissection of body and space today carried out through digital technologies, but with purely analog and material means» (O'Donnell, 2007). In this sense, *Triadic Ballet* is not merely a historical testament to modernist avant-garde but an operational model for understanding the role of color as a spatial and performative tool. Its strength lies in its ability to fuse theory and practice, form and function, body and color, in a unified vision that continues to inspire contemporary artistic research.

Schlemmer's influence is evident in many contemporary immersive and installation practices, where light and color play central roles in the sensory construction of space. Danish artist Olafur Eliasson, for example, uses color to alter environmental perception and stimulate a corporeal and psychological awareness in the viewer. In works such as *Your Rainbow Panorama* (2011) or *Room for One Colour* (1997), color is not a painted surface but an atmospheric, immersive, perceptual environment. He states: «Color can be a means of sculpting time and space in the mind and body of the viewer»(Olafur Eliasson O.,2006), giving a vision in perfect alignment with Schlemmer's exploration.

Orazio Carpenzano theorizes a stereoplastic space, which splits thanks to motion graphic techniques. This is a space where beyond the usual forms of movement, friction and resistance can be recorded, not cancelling out motion but transforming it into complex forms no longer perceptible by the eye alone; a space that aims to be the 'configurative action of life', capable of revealing and displacing the secrets of the visible and invisible, the material and the immaterial (Russo, 2015). Within the NURBS system of 3D software, the research shifts toward replacing the traditional anatomical model of the human body with virtual trajectories.

In France, the Adrien M / Claire B operates in the field of multimedia performance creation. The program that defined their artistic path, eMotion, is a tool capable of creating moving objects (lines, points, letters, particles, etc.) based on physical forces, representing real-time images captured and manipulated on stage. In *Hakanaï* (in Japanese, fragile, transitory, evanescent), a danced solo, images were animated live in relation to the dancer's movements and the rhythm of the sound, also performed live, achieving exactly that surreal dreamlike sensation sought by the artist. The concept of "stereometric scenarios" proposed by Schlemmer is more relevant today than ever. In contemporary immersive and interactive experiences, the audience is often involved not as a passive observer but as a dynamic component of a perceptual space, where color still defines the relationship between bodies and spaces. Schlemmer remarkably anticipated the possibilities now offered by artificial intelligence, algorithms and spatial computation: a *moving architecture* of color, where form, body, and environment are indissolubly connected.

By merging body, space, color and geometry, Schlemmer introduced an approach that not only broke with traditional theater but also evolved into a synesthetic and multidimensional system, foreshadowing many of the artistic experiments that would define the century. The stage he envisioned is not a mere space to be filled, but a complex organism, where every element - dancers, costumes, lights, movement - engages in dynamic and retroactive relationships, giving life to a constantly fluid and ever-changing reality.

Conclusions

Schlemmer was not only an innovator of theatrical form but also a true precursor to contemporary aesthetics, including virtual and AI ones. The use of color as a spatial code, costumes as *moving architectures* and choreography as a perceptual grammar: all of these elements reveal a unified and profound vision of stage art. In this context, each component, from the body to the light, from movement to color, collaborates to create an immersive, almost abstract experience based on the

sensory manipulation of the audience. For Schlemmer, the human figure becomes the device through which perception is explored and redefined. It is "the measure of all things," not merely as an individual but mediated by a language that transcends classical conventions. In an era where digital technology and artificial intelligence are reshaping stage design, Schlemmer's lessons remain incredibly relevant. His stage is not just a space of perceptual transformation, but a meeting point between reality and abstraction, between matter and imagination. Therefore, it is not just a chapter in the history of the avant-garde but a theoretical and operational model that continues to inspire and shape hybrid, intermedial artistic practices. His ideas, fundamental to the performing arts of the future, place the interaction between body, space and technology at the center. Schlemmer's "stereometric stage" with its visionary essence, remains a design paradigm for a new conception of theatrical experience.

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A magnificent and gloomy city. The Significance and Ecological Aspects of Achromatic Colors in Urban Landscapes

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Abstract

Achromatic colors—white, black, and shades of gray—play a crucial role in shaping the visual environment of modern cities and serve as key components of sustainable and functional urban landscapes. Unlike chromatic colors, they are often perceived as neutral and undervalued in analyses of urban aesthetics and ecological impact. This article examines the importance of achromatic palettes in urban environments, their psychological effects, and their influence on spatial perception, urban heat regulation, and pollution resilience. It explores the cultural significance of white, black, and gray as both symbolic and functional tools in urban design. Through interdisciplinary analysis of architectural case studies, the research demonstrates how these colors reflect shifting urban values—serving either as frameworks for chromatic palettes or as dominant color schemes in their own right.

Keywords: achromatic colors, urban landscape, ecology, thermal regulation, visual perception, color semiotics

1. Introduction

Modern cities face the challenge of creating sustainable, functional, and aesthetically balanced environments. Color schemes in urban landscapes profoundly impact both residents' emotional well-being and microclimates. Contemporary ecological color theories in urban design argue that "a city's color identity should emerge organically, rooted in local hues shaped by geography, climate, natural surroundings, and light conditions" (Griber, 2023, p. 60). The existing environment possesses what James J. Gibson called affordances and gestalt psychologists termed Aufforderungscharakter der Dinge—a "demanding character" that guides color choices (Griber, 2023, p. 63). Today's urban planners applying these theories create environmental color palettes for new developments, using them to inform decisions (Waygood, 2017). Achromatic colors appear in these palettes as complementary tones since natural environments are typically polychromatic. Their urban application depends on four factors: construction materials, tradition, functionality, and cultural symbolism.

Though lacking hue, achromatic colors are far from neutral. They structure visual rhythm, influence light levels, and even regulate urban heat balance. A balanced use of these colors reduces visual noise, promoting focus in interiors and harmony in public spaces.

White visually expands spaces and serves ecological functions (e.g., increasing albedo in southern latitudes). Culturally, it carries diverse meanings—purity, minimalism, freshness, but also melancholy. It demands high maintenance (repainting or cleaning) to preserve its pristine appearance.

Gray offers visual compromise between extremes, though it is often associated with utilitarian materials like concrete and asphalt. Pragmatic and undemanding in use, it hardly ever causes rejection among local residents. "This colour is not exalting, but at the same time it can be easily combined with any other colour, chromatic or achromatic" (Zennaro, 2017, p. 92).

Black adds depth and highlights details but risks heaviness and gloom if overused. A staple of minimalist architecture, it periodically trends in avant-garde projects. Like white, it requires upkeep to avoid fading into gray.

Achromatic colors serve dual aesthetic roles: as neutral backdrops that accentuate architectural forms and urban dynamism, or as striking contrasts (via white/black) that disrupt the color scheme.

Global cities like Copenhagen, Tokyo, and Berlin deploy achromatic palettes to visually organize urban space. Architecture, public transportation, street furniture, building facades, and landscaping all work with an achromatic background to create a more manageable and adaptable environment. The most successful cases balance achromatic bases with natural greenery and artistic accents, fostering vibrant yet cohesive urban fabrics.

2. Methods

This interdisciplinary study draws from humanities, geography, anthropology, and social sciences. Using semiotic analysis, we examine the color palette of urban landscapes as a system of signs (Lavrenova, 2023), complemented by comparative historical, geographical, and interpretive methods. The study examines achromatic colors based on their symbolic functions and how they relate to the signified. We consider the multiple meanings of color in architecture, how it interacts with construction materials and connotations. The study reviews extensive theoretical and applied research to identify patterns in achromatic color semantics and their ecological impacts.

3. Functionality and Sustainability

White and light-gray surfaces reflect solar radiation, significantly impacting urban microclimates. These light-reflective surfaces can reduce the urban heat island (UHI) effect by increasing albedo, lowering ambient temperatures by up to 4°C in cities like Los Angeles and Athens. “Solar reflective urban surfaces (white roof and light-colored pavements) can increase the albedo of an urban area by about 0.1. In turn, increased albedo of urban and human settlement areas can decrease atmospheric temperature and counter some of the anticipated temperature increase from global warming. As such, this may be an effective strategy to complement climate mitigation efforts as a way of further slowing the rate of global temperature increase in response to continued greenhouse gas emissions” (Akbari, 2012, p. 8).

However, the ecological impact is not straightforward and implies an environmental conundrum. Producing synthetic white materials (e.g., titanium dioxide-based paints) often involves high carbon emissions, and maintaining light surfaces in polluted areas requires frequent cleaning, increasing water and chemical use. This drives demand for eco-friendly innovations like photocatalytic coatings, which preserve brightness while neutralizing pollutants—as seen in Milan’s Palazzo Italia (Figure 1). Cities leverage light achromatic palettes for both ecological and cultural synergy. Singapore’s “white urbanism” combines reflective buildings with vertical gardens, merging heat reduction with biophilic design.

On the other hand, black and dark-gray surfaces absorb heat, risking localized overheating, especially in dense urban areas. Thus, architects typically reserve black for temperate and northern latitudes—with exceptions like Ricardo Bofill’s Xanadu residential complex near Alicante, Spain, a climatic paradox on the La Manzanera resort (Figure 2).

The most common dark-gray urban surface—asphalt—becomes soft in heat, causing problems for pedestrians and drivers. Conversely, gray tones introduced in high-latitude cities may exacerbate psychological distress. As Booker and Angelo (2017) note, “with a solar angle variation between 3 to 50, and with overcast, bluish light more common than direct sunlight (Matusiak 2017), colour is an essential human factor, not just in terms of regional cultural identity and history, but also as a condition for well-being.”

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Figure 1. Palazzo Italia. Expo Milano 2015[1]

Figure 2. Xanadu residential complex near Alicante, Spain[2]

4. Semantics of Achromatic Colors

4.1. Gray and Black as "Absence of Color/Light" and "Signs of Distress"

The proverb "All cats are gray at night" reflects how darkness strips objects of chromaticity. At night, we only see white, black, and gray. White naturally appears under even minimal light, explaining its use for nocturnal mythic figures (e.g., Mexico's La Llorona or Slavic "woman in white"). Light colors turn gray; black merges with darkness, achieving its true suchness.

"Darkness falls within a system of symbolic values where colours are ascribed to meanings that are related to one another. In this system, darkness is often understood as opposed to brightness, whiteness, generally meaning light, purity, life—thus making darkness its polar opposite: a lack of light, of purity, of life. As with any binary, darkness (blackness) and light (whiteness) are often inextricably linked, which allows to temper the correlation between obscurity and the North, as with dark inevitably comes light" (Chartier et al., 2021, pp. 11–12).

In colorful daytime urban spaces, everyday perception reserves "color" only for chromatic tones, so "architecture splits into black-and-white and colored structures" (Rieger, 1976, p. 11). As in any language, achromatic signs (in this case, color in urban space will be zero) require chromatic (non-zero) counterparts to form meaningful systems (Griber, 2012, pp. 206–207). Michel Pastoureau traces this chromatic/achromatic dichotomy (like "yes" and "no") to late 15th-century European thought (Pastoureau, 2008, p. 211).

A zero, or empty sign represents meaning without a specific form—what Yulia Griber (2018, p. 24) calls "a meaning without form, the absence of a positive signifier that should exist by analogy with other syntagms where signs of the same meaning have explicit form." In cities, shades of gray typically function as this empty sign due to their neutrality, even discreetness, and common use in infrastructure (pavements, fences).

Gray surfaces show less visible staining, making them practical for industrial and transit zones. However, this grayness typically comes from unfinished concrete—essentially a cost-cutting measure. The phenomenon of gray urban development became characteristic of residential districts in rapidly growing cities. A prime example are the Soviet-era Khrushchyovka apartment blocks (1955-1963)—standardized five-story buildings commissioned by USSR leader Nikita Khrushchev. Originally meant as temporary 20-year housing, many remain in use today. Colloquially called Khrushchobas (blending "Khrushchev" and the Russian word "trushchoba" meaning "slums"), these gray complexes exacerbate mental fatigue and depressive-aggressive moods among residents—problems rooted in their social history as housing for rural migrants and later, low-income urban dwellers. This gray trend continued until the end of the 20th century (Figure 3).

[1] https://www.nemesistudio.it/en/portfolio/pad-ita-eng/

[2] https://api.interior.ru/media/thumb/952x708_5/images/gl2/15-01-2022/RicardoBofill_13_.jpg

This type of achromatic development, which should be perceived as a zero, becomes what Charles Peirce called an indexical sign, or a sign of distress (Griber, 2018, p. 26). "Such, for instance, is a piece of mould with a bullethole in it as a sign of a shot; for without the shot there would have been no hole; but there is a hole there, whether anybody has the sense to attribute it to a shot or not" (Peirce, 2000, p. 218). Like Peirce's example, the grayness signals not just poor aesthetic standards and limited budgets (Efimov, 1981, p. 17), but inadequate urban social policies.

Abandoned buildings similarly register as "gray spaces" in public consciousness. Even originally colorful facades eventually decay to reveal structural grays. The most universal marker of abandonment—functioning like Peirce's bullet hole—are the black voids of glassless windows. When I ask students how to spot abandoned buildings from a distance, they consistently identify these dark window cavities, catching no light, reflecting no sky (Figure 4). This indicator works primarily in temperate/northern climates where glazing remains essential—unlike in Global South slums where unglazed windows are common.

Figure 3. Kupchino District, Saint Petersburg (1970s housing development), Russia[1]

Figure 4. Kadykchan, Magadan Region, Russia[2]

Black also carries other tragic associations—most visibly in fire-damaged structures.

Dirty brown (while not truly achromatic) functions similarly to gray as an indicator of material scarcity and color indifference. The slums of the Global South—such as Dharavi and Kibera—built from raw stone, clay, salvaged metal, and slate, blend into a gray-brown color palette.

As Griber (2018, p. 26) observes, gray ruins (covered in dust or with worn-off paint) signal lost control over urban color space, haphazardness and unmanageability of urban change. "The aspect that most affects the appearance of a city is the grey colour coming from dirt deposited on the buildings and walls" (Zennaro, 2017, p. 92). Dust and smog accelerate this—Cologne Cathedral's sandstone has darkened to deep gray from centuries of soot and particulate erosion, now being replaced during restoration with light-gray trachyte volcanic stone.

4.2. Gray and Black as Fashion Trends

Historically, black and gray—associated with specific construction materials—have been socially accepted and aesthetically pleasing colors. For example, the noble silver-gray hue of untreated wood (particularly aspen) develops naturally in northern or high-altitude regions due to weathering. Over time, this color gains cultural value, as only heritage buildings—primarily churches—survive and are often preserved in skansen-like open-air museums (Figure 5).

Black marble and black tuff are luxurious materials that elevate their associated shades to symbols of wealth. While white marble was used for royal palaces and elite spaces, black marble became the refined choice for opulent private or nationally significant memorials. Black tuff, a porous volcanic

[1] See the image source: https://avatars.dzeninfra.ru/get-zen_doc/271828/pub_67cff3bdc7307b6c9d5608c1_67cffbc108fe856a2e405c93/scale_1200

[2] See the image source: https://avatars.dzeninfra.ru/get-zen_doc/271828/pub_680a0139b44a37324c0d4f79_681934fc37ab0a2d304f492f/scale_1200

rock formed from ash, is regionally specific—abundant in places like Armenia, where it is used for construction (notably in Gyumri). It is frost-resistant, easy to work with, and provides excellent thermal and sound insulation. Architects also use it for striking facades, such as Moscow's Poroda mansion (Figure 6) near the Bolshoi Theater.

The modern embrace of black in urban design began with minimalism. Black makes buildings stand out, turning them into neighborhood landmarks or city icons. Architects favor it for its bold disruption of the environment—its light-absorbing quality gives black structures a hypnotic presence, drawing attention while "swallowing" their surroundings. Matte black facades became a hallmark of daring 20th-century designs (Figure 7). Black accents in Melbourne's streetscapes or New York's skyscrapers add contrast and sophistication, though they require careful application to avoid alienating viewers.

Fiture 5. St. Nicholas the Wonderworker Church in Kondratyevskoye Village (Vorzogory), Arkhangelsk Region, Russia[1]

Fiture 6. Poroda Mansion in Moscow, Russia[2]

Figure 7. Jefferson Sheard Architects' Soundhouse, Sheffield, UK[3]

Achromatic palettes carry deep symbolic weight, often linked to modernity, minimalism, and neutrality. Gray and silver dominate high-tech skyscrapers, though their reflective surfaces blur their perception as truly achromatic. "Large plates of glass work like mirrors duplicating external environments, changing colour with weather. Tinted glass panels and ascetic steel ornaments are applied to add finer grain and texture to the otherwise monolithic facades. Daylight almost paints steel detailing in contrast to the building's skin" (Zimnicka et al., 2022).

[1] See the image source: https://mpei.ru/news/Pages/newsItem.aspx?newsID=3135
[2] See the image source: https://dmitrovka9.ru/osobnyaki.html
[3] See the image source: https://i.pinimg.com/736x/36/e4/8c/36e48cfd870bfae8679567540bfbbfe9.jpg

In cities like Berlin and Tokyo, gray tones embody contemporary pragmatism. In innovative designs, architects use gray to highlight unconventional forms, which frame buildings as works of art in themselves (Zennaro, 2017, p. 90).

Even in wealthy regions like Norway—where traditional homes were once red—gray has become fashionable in residential architecture, heavily influenced by marketing trends. "Critical factors accumulate to generate what we call 'chromatychiphobia': time pressure, decision exhaustion, peer pressure, ridicule over inappropriate choices in social media, the complexity of colour design, and the wealth of contradictory advice. The volume of choice seen in the context of trend exemplification, and not least of all economic cost, are all powerful motivations for a fear of making wrong choices that drive towards the solutions exemplified in safe trend colours. This applies to the architectural profession as much as to the public, and is compounded by the developer's suspicion of any factor that might increase time and material costs" (Booker & Angelo, 2017, p. 106).

"The current white-grey-black is now a default 'no-risk'standard. <…> From this situation, it will become increasingly difficult to re-engage chromatic qualities. In an area, which has drifted down to achieve a chromatic null point, any attempt by an individual to re-introduce colour will be treated as a contrarian aberration and will be subjected to ridicule" (Booker & Angelo, 2017, pp. 106–107).

4.3. White—The Color of Spirituality, Power, and Wealth

White is one of architecture's most widespread and positively connoted achromatic colors, though it carries inherent duality. Cultural geographer Yi-Fu Tuan (1990, p. 25) describes it: "White: (positive) light, purity, spirituality, timelessness, divine, (negative) mourning, death."

Across religions, white adorns temples and memorials that serve as visual and symbolic focal points. The Taj Mahal—originally a symbol of grief, now a tourist attraction—dominates the vast landscape through its scale and location at the riverside.

Traditionally, white's prestige comes from materials like limestone and marble—expensive and historically tied to wealth. In medieval Russia, princes resided in "white-stone chambers," and churches were built from white limestone (Figure 8). In Europe, white marble was predominantly used, including for the Parthenon—a symbol of the classical era. Though the real Parthenon's Pentelic marble has yellowed with age, it remains symbolically white in public imagination and depictions.

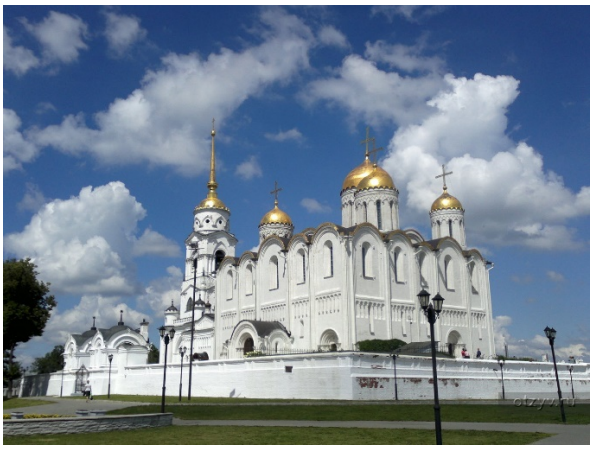

Figure 8. Holy Dormition Cathedral in Vladimir, Russia[1]

White has long been associated with power and government buildings, though this connection varies across time and geography. Examples include the 18th-century Jag Niwas palace (now a hotel) of white marble on Lake Pichola in Udaipur, India, or the obligatory white columns of European royal

[1] See the image source: https://f.otzyv.ru/f/12/05/101689/7090/0307120126360.jpg

palaces during the Classical period. One of the most recognizable symbols of power is the White House (Figure 9)—originally built and whitewashed with lime in the early 19th century but officially named by Theodore Roosevelt in the early 20th century, completing the semiotic word-concept-object triangle. Interestingly, the term "White House" was later adopted metaphorically in the Soviet Union and post-Soviet states to refer to municipal administrative buildings, reinforced by their light-colored facades that made them visual landmarks in cities (Figure 10).

The concept of the "White City" carries spiritual meanings, linking physical landscapes with mystical space. Traditionally, white architecture has been most common in Mediterranean cities, where its use is ecologically practical and typically achieved with lime-based paint. However, one city stands out for its nearly complete use of white marble: Ashgabat, Turkmenistan. Rebuilt in this style after a devastating earthquake in 1945, Ashgabat's marble helped establish white as a national symbol after independence. The first president even issued a decree requiring local cars be repainted white, reinforcing marble as a source of pride and white as a symbol of authority.

Figure 9. The White House, United States[1]

Figure 10. "White House" (City Administration Building), Lyubertsy, Russia[2]

Urban spaces dominated by white—like the iconic architecture of Santorini or Barcelona's modernist facades—evoke purity and timelessness. Yet excessive use of achromatic schemes can feel sterile, diminishing emotional engagement. Balanced integration with natural elements (greenery, wood textures) is key to psychological comfort.

5. Conclusions

Achromatic colors are vital for aligning aesthetic and semantic characteristics with ecological goals in urban design. White, black, and gray carry centuries of layered meanings. Their strategic use can improve microclimates but requires thoughtful material selection and public engagement. By rethinking neutrality as an active design force, cities can harmonize visual coherence, sustainability, and human well-being. Successful implementation demands attention to climatic, cultural, and psychological aspects. When integrated wisely, these colors help minimize visual pollution while creating cohesive and comfortable urban atmospheres. The future of sustainable cities depends on the thoughtful interplay of color, form, and ecology.

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[1] See the image source: https://avatars.mds.yandex.net/i?id=10ae655cb53e89c92829fca1d7ecf44bf0319566-4550834-images-thumbs&n=13

[2] See the image source: https://moscowiki.ru/files/7/7d/Люберцы_администрация_1.jpg

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Color and Design

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Colouring outside the (stereotypical) lines: Rethinking colour and gender in design

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Abstract
This paper investigates the role of colour in shaping gendered perceptions of consumer products and its implications for inclusive design. Drawing on a qualitative study with design students, it examines how all three colour properties —hue, saturation, and lightness— interact to reinforce or challenge binary gender associations. Findings indicate that lightness strongly signalled femininity or masculinity, saturation extremes reinforced binary readings, and mid-range values often fostered ambiguity and androgyny. The results also show how stereotypes persist when designers rely uncritically on cultural codes yet demonstrate colour's potential to disrupt gender norms and expand aesthetic possibilities. Building on these insights, the paper proposes the foundation of the *Colour + Gender Framework*—a tool to guide more intentional chromatic decisions in product design. The framework supports strategies that move beyond stereotypes, destabilise reductive binaries, and promote more inclusive and equitable design outcomes.

Keywords: colour and gender; gender-sensitive design; visual attributes; colour design; colour meaning

Introduction

In recent years, numerous studies have examined the complex interconnections between colour, gender, and product design. This relationship has been described as encompassing historical, social, psychological, and economic dimensions (Ben-Zeev and Dennehy, 2014; van Tilburg et al., 2015; Grisard, 2019; Dantas et al., 2021; Bideaux, 2022; Moshary, Tuchman and Vajravelu, 2023). Colour plays a central role in shaping the initial perception of gendered products, influencing consumer behaviour, and contributing to the social construction of identity. The gendering of colour affects consumer choices, reinforces societal stereotypes, and creates ongoing challenges for designers striving to produce inclusive and equitable products (Ehrnberger, Räsänen and Ilstedt, 2012; Ben-Zeev and Dennehy, 2014). Colour functions as a highly powerful and pervasive cue in design, frequently deployed to shape and perpetuate gender biases and stereotypes (Koller, 2008; Grisard, 2017; Canlı, 2018). Concerning hue, the cultural assignment of pink to girls and blue to boys has been historically constructed through toys, clothing, and mass media rather than reflecting innate preferences. This construct gradually normalised over time (Dantas et al., 2021). The association of pink with femininity and blue with masculinity gained dominance during the mid-20th century, particularly after World War II, as a byproduct of Western capitalist strategies aimed at segmenting markets and boosting consumption (Paoletti, 2012; Canlı, 2018; Grisard, 2019; Ma and Wang, 2024). Before the 1940s, however, pink was not firmly coded as feminine; it was even considered "stronger" and therefore more suitable for boys in the early 20th century (Paoletti, 2012; Ben-Zeev and Dennehy, 2014; Grisard, 2017). Today, pink is widely deployed to mark products as "for girls/women," while the rest of a product line is implicitly framed as "neutral" or "masculine" (Bideaux, 2022). Examples range from razors and toolboxes to earplugs, pens, and even laxatives. The personal care market, for instance, is particularly gendered, with over 80% of its products explicitly targeted by gender (Moshary, Tuchman and Vajravelu, 2023).

Among product attributes, colour—especially hue—is the most common indicator (98%) consumers use to identify a product's gender target, followed by name and description (Ibid). Beyond hue, other

colour attributes also contribute to gendered coding. van Tilburg et al. (2015) argue that products with lighter tones, multiple colours, or shiny surfaces are generally associated with femininity. In contrast, darker tones, fewer colours, or matte finishes are linked with masculinity. Supporting this, a cross-cultural study in nine countries found that "feminine" was predominantly associated with light shades, while "masculine" was related to dark shades (Jung and Griber, 2019).

Designers, however, often rely on generalised beliefs and stereotypes about gender. Historically, design aimed at one sex has frequently been based on misleading assumptions (Stilma, 2006). Such reliance risks producing homogeneous solutions that reinforce narrow ideas of masculinity and femininity, overlooking the diverse needs of broad consumer groups, particularly women (McMahon and Kiernan, 2017). For this reason, it is essential that designers critically reflect on their gendered perceptions and the ways these influence their design decisions, moving beyond stereotypes to close the gap between designers and users (Esfahani, 2020).

Indeed, contemporary design practices increasingly need to challenge traditional gendered colour coding to appeal to broader and more diverse audiences. Addressing this issue requires a multi-faceted approach, ranging from rethinking colour symbolism to adopting more inclusive design methodologies and critically examining the biases embedded in product aesthetics. Several strategies have emerged in this regard. One is (i) the adoption and evolution of gender-neutral and unisex approaches, which move beyond dichotomous thinking and prioritise individual needs over rigidly defined gender roles (Ehrnberger, Räsänen and Ilstedt, 2012). This strategy deliberately avoids strongly gendered attributes in colours, forms, and other product characteristics (Esfahani, 2020). A second is (ii) the deconstruction of traditional pink marketing, which historically conditions female consumers from childhood to associate pink with femininity. Today, many women actively reject this association, and the strategy is widely criticised for instrumentalising feminist discourse while perpetuating inequalities (Bideaux, 2022). A third is (iii) the use of satire and reappropriation to subvert stereotypes, for instance by deploying pink ironically or humorously to symbolically undermine masculinity (Bideaux, 2018). Finally, a fourth strategy is (iv) the visualisation of gender norms through product language inversion. Applying the traditionally "male" design language of a drill to a hand blender, and vice versa, exposes the invisible meanings and values embedded in artefacts. Such inversions destabilise preconceptions and open new ways of valuing characteristics not conventionally associated with a product—for example, beauty and simplicity in the case of a drill (Ehrnberger, Räsänen and Ilstedt, 2012). In parallel, recent studies have advanced new frameworks for designing beyond the binary. Labarta, Ingaramo and Mattioli (2024) propose three categories of gender-sensitive strategies: (i) cue-free design, which removes explicit gender markers to avoid reinforcing stereotypes; (ii) gender-shift design, which plays with or inverts gendered scripts, often ironically; and (iii) flexible design, which embraces ambiguity and complexity to broaden inclusivity without erasing colour altogether.

Methodology

The study adopted qualitative methods across two phases: a five-day workshop on *Gender and Design* with design students, and a subsequent analysis of the collected data. The workshop generated insights into gender awareness in product design, while the analysis focused on colour as a key semantic element shaping perceptions of gender categories. Together, these phases informed five colour design assumptions, forming the basis of a forthcoming *Colour + Gender Framework* for design.

A. Data collection phase: the workshop

The workshop took place from March 3–7 at the University of Sassari, Italy, with 23 Bachelor of Design students across all years. It aimed to foster gender awareness in design processes by questioning stereotypical assumptions. Hence, the intended learning objective (ILO) of the workshop was meant to foster "awareness and knowledge of one's own cognition" (Anderson, 2009, p. 46),

particularly concerning design decision-making. This overarching ILO was supported by a set of secondary ILOs, which progressed from lower- to higher-order thinking skills (i.e., from understanding to analysing and creating), and from concrete to abstract knowledge (i.e., factual to conceptual) (Ibid). Each activity was carefully crafted and structured around these secondary ILOs.

This paper focuses on the first part of the workshop, which explored how aesthetic choices—especially colour—shape a product's gender character, either reinforcing or challenging stereotypes. The goal was to address the first and foundational secondary ILO, centred on factual knowledge and understanding as a thinking skill, enabling students to analyse the gendered nature of consumer products. An introductory lecture and mapping activity framed this exploration.

a.1. Introductory Lecture: A 25-minute lecture introduced the concept of gendered attributes of consumer products, presenting a taxonomy beyond the binary—feminine, masculine, androgynous, i.e., showing both masculine and feminine traits, and gender-neutral, i.e., where neither is present. (Labarta, Ingaramo & Mattioli, 2024). Conceived as a flexible tool rather than a rigid system, the taxonomy encouraged students to reflect on underlying biases. The lecture set the stage for the first activity: mapping product images on a two-axis diagram according to these four categories.

a.2. Mapping activity: Students, divided into six groups, worked on three product categories with gendered associations: electric razors (ER), hand blenders (HB), and electric screwdrivers (ES). These products were selected because they belong to categories often associated with stereotypically gendered imaginaries that intersect with self-identity and where there is a tension between the domestic and the professional or the private and the public (i.e., self-care, kitchen work, and handwork). Each group mapped 24 products of their assigned category onto a diagram structured by masculine–feminine (horizontal) and gender-neutral–androgynous (vertical) poles. Consequently, four borderline areas or quadrants are created on the map. The activity unfolded in three analogous and sequential steps: working with silhouettes only (Step 1), achromatic images (Step 2), and chromatic images (Step 3). Groups negotiated placements until reaching consensus. In addition to mapping, groups assigned to the same product category (e.g., Groups 1 and 2 for ER) were later encouraged to compare their canvases and discuss differences in product placement and perceptions. The activity concluded with a collective reflection on how shape, form, and colour influence perceptions of gender, when stereotypes dominate, and how products might be reimagined beyond binaries.

B. Data analysis and interpretation

This phase was initiated by preparing the collected data for analysis. The physical maps from Steps 2 and 3 were digitally reconstructed in Adobe Illustrator. Subsequently, colour palettes were derived from the images of each product to enable a more detailed chromatic analysis. The palettes were organised according to a Just Noticeable Difference (JND) criterion, aimed at minimising perceptual colour differences, while preserving the proportional distribution of colours originally present in each image. These proportions were qualitatively estimated based on visual dominance. Each palette's colours were therefore ordered from the most prevalent (dominant hue) to the least. Consequently, three categories of colour palettes were identified: (i) monochromatic, (ii) polychromatic with a dominant colour, and (iii) polychromatic with balanced proportions. Also, the corresponding RGB, CMYK, HEX, and HSB codes were extracted for each colour of the palette. Using the HSB model, five levels were defined to classify the colours according to their lightness and saturation (low, medium low, medium, medium high, and high). Products were assigned ID codes (e.g., HB01) for systematic tracking. Finally, in the reconstructed canvases, the product images were replaced with their corresponding colour palettes, thereby enhancing the visualisation of the chromatic dimension.

The analysis focused primarily on how colour properties—hue, saturation, and lightness—shaped gender perception along the defined axes. First, lightness (Workshop Step 2) was studied to identify patterns in the association between different levels of lightness in products and the gender categories defined in the canvas. This made it possible to determine how the lightness of the products positioned along the Masculine, Feminine, Gender-Neutral, and Androgynous axes—and their respective quadrants (1 to 4)—was perceived, and therefore, what role lightness played in these associations. Then, product placements were compared between Steps 2 and 3 to clarify the role of the chromatic component in product associations with the defined gender categories. The comparison enabled us to track movements of products from one canvas to the other, observing which products shifted position (axis or quadrant) once chromatic properties were added. It was also possible to analyse which products maintained their coordinates; which colour combinations were repeatedly associated with a specific quadrant or position; which dominant colours were primarily linked to the defined gender categories; which secondary colours were associated with those categories; and how hue, saturation, and lightness may serve as determining factors in the perception of gender categories, among other aspects. An intergroup analysis was also conducted on the results obtained by both groups who worked with the same product category, comparing the Step 2 and Step 3 canvases. This analysis identified consistencies and differences in product positioning and, consequently, in their association with the different gender categories defined in the canvases. Here, the focus was on examining which products were located in the same quadrant/axis/position according to both groups, as well as which were defined as "ambiguous" by both groups (that is, positioned in borderline zones between one axis and another). In some instances, corroborations were carried out using the Step 1 canvas (where products were represented only by their silhouettes, i.e., purely formal appearance), in order to determine whether form (in some cases archetypical) exerted a more substantial influence on the perception of specific products and therefore reinforced their association with the defined gender categories (e.g., an object resembling a weapon = masculine).
To better understand how the three colour properties affect gender perception, a matrix traced product reclassifications from Step 2 to Step 3. This relational structure highlighted which colour properties prompted changes and revealed broader tendencies in how hue, saturation, and lightness reinforce or challenge normative gender associations in product design.

Results
The insights from the analysis relate to general observations on students' interpretive challenges and a set of assumptions describing the role of colour in gender perceptions.

A. Challenges in interpreting gender beyond the binary
Each group of students produced three maps, one for each step. Their progression revealed common interpretive challenges. First, many groups struggled to separate a product's shape from its function, often assigning gendered meanings based on learned associations rather than formal qualities. For example, a screwdriver was frequently labelled as masculine—not for its appearance, but because its function is traditionally linked to male roles. This highlights the influence of internalised gender norms embedded in everyday products. A more significant difficulty emerged when students were asked to move beyond binary classifications. While readily identifying objects as feminine or masculine, they hesitated to position them along a broader, more diverse spectrum. Their hesitation was often accompanied by caution, especially during the early stages of the activity. Several students sought reassurance that their interpretations were respectful and appropriate, revealing a degree of anxiety and uncertainty around navigating gender issues through design. Despite growing awareness of gender diversity, they lacked confidence in engaging with it. Even so, their interpretations across the three mapping steps provided valuable insights. The following section examines how gendered meanings were gradually constructed through visual information, from shape to colour.

B. The role of colour in gender perceptions: assumptions on HSB relational patterns

This section examines how hue, saturation, and lightness (HSB) interact to convey gendered meaning across product categories, through five emerged assumptions:

b.1. Lightness by itself is a gender cue: Mapping results from Step 2 show that lightness strongly influences gender perception, both independently and in combination with formal features such as shape and finishing. Lighter neutrals consistently aligned with femininity, while darker tones clustered with masculinity. In Step 3 (chromatic images), this pattern persisted. Moreover, shifting the lightness of one of the colours in a palette from dark to light, and using it together with an accent of a saturated hue, often altered a product's gender reading. For example, in one case (HB03), a dark neutral combined with a pink accent produced an identity that leaned feminine but remained ambiguous. The comparison of desaturated and saturated maps confirmed the foundational role of lightness, though not an exclusive one. In four out of six groups, more than 60% of images shifted between steps, suggesting that while lightness and shape are influential, other HSB properties and their interplay often override them.

b.2. The relationship between colours contributes to genderisation and degenderisation: Beyond lightness, colour combinations within the palette— monochromatic, polychromatic with a dominant hue, or polychromatic with balanced proportions—also play a role in constructing gender perceptions. Feminine-coded palettes often paired a light neutral with a subtle accent, while masculine-coded ones tended to be monochromatic, dark, or polychromatic with vivid colours. Androgynous readings emerged when "feminine" accents contrasted with dark neutrals (e.g., HB16) or saturated primary colours were accompanied by light neutrals (e.g., HB08). Chromatic relationships also pushed degenderisation. Gender-neutral palettes leaned towards monochrome, often relying on extreme lightness or darkness (e.g., ES05), whereas androgynous ones involved more balanced or ambiguous polychromatic pairings. These cases demonstrate that gender coding depends not only on individual HSB values but also on how colours are paired and contrasted within the palette.

b.3. Low and high saturation are associated with binary assumptions: Extremes of saturation reinforced binary perceptions. Low saturation combined with high lightness produced the pastel and soft shades commonly linked to femininity (e.g., ER18). In this case, hue played a secondary role, as feminine-coded palettes appeared across the colour wheel—from violets and blues to reds and oranges. Lightness and saturation carried the weight of meaning in these cases, embedding stereotypical feminine scripts through delicate, pastel tones aligned with a Western-centric image of femininity. By contrast, masculine-coded products typically employed blue or red hues with high saturation and brightness, resulting in palettes that appeared more vivid and energetic than their feminine counterparts (e.g., ES24).

b.4. Medium-range values of lightness and saturation contribute to ambiguity, especially leaning towards androgyny: Ambiguous and androgynous perceptions most often stemmed from mid-range values of lightness and saturation. Across categories, chromatic images assigned to the androgynous axis pervasively displayed low-medium or high-medium values of both saturation and lightness (e.g., HB17). This differs from gender-neutral palettes, which were mainly monochromatic and located at the extremes of lightness (i.e., very light or very dark). Hence, while neutrality arises through the absence of chromatic contrast, androgyny emerges through mid-range combinations that blur binary boundaries without erasing colour.

b.5. Formal language can override colour in archetypical products: While colour properties significantly shaped perceptions, the analysis also highlighted the enduring influence of formal language—shape, surface treatment, and design details—on gender coding. In hand blenders (HB) and electric screwdrivers (ES) categories in particular, form often outweighed chromatic cues. ES products consistently borrowed from masculine-coded archetypes such as gun-like silhouettes and oversized ergonomic features, which anchored them firmly within the stereotypically masculine domain even when colour configurations might have suggested neutrality or ambiguity (e.g., ES01). Similarly, in HB, the association of strength and technical performance with certain forms reinforced masculinity regardless of the colour palette (e.g., HB19).
These results confirm that colour is better understood as the interplay of HSB properties rather than a hue-centred phenomenon. Each colour property—hue, saturation, and lightness—contributes differently, and to varying degrees, to the gendered perception of products.

Discussion
The analysis results shed light on the narrative and underlying mechanisms bridging colour systems and their role in shaping gender imaginaries embedded in consumer products. Here, we discuss (i) how colour is confirmed as a powerful and influential gender cue, (ii) the pressing need for designers to critically engage with the socio-cultural and historical dimensions of chromatic choices, and (iii) we propose the *Colour + Gender Framework* hoping it leads to a more critical and intentional relationship between design and gender awareness.

A. Colour remains central in shaping gender perceptions
Our findings supported and expanded the view that colour remains one of the most powerful cues in product gendering (Canlı, 2018). Lightness emerged as a primary signal, with lighter tones aligned with femininity and darker tones with masculinity. This pattern echoes cross-cultural associations reported in earlier studies, where "feminine" was predominantly linked with light shades and "masculine" with dark ones (Jung and Griber, 2019). In combination with saturation and hue, our analysis further showed that the pink–blue dichotomy continues to hold, reflecting the historical construction of these codes as market strategies (Paoletti, 2012; Canlı, 2018; Dantas et al., 2021).
By contrast, gender neutrality frequently appeared in "hue-less" palettes where saturation was near zero. These schemes drew on male-oriented aesthetics in which colour is deliberately erased to appeal to a broader audience while maintaining a masculine-coded baseline. This confirms critiques that "neutral" in design is rarely neutral, but often a disguised masculine default (Stilma, 2006; McMahon and Kiernan, 2017; Canlı, 2018). While marketed as universal, such palettes carry the symbolic weight of male-coded attributes presented as a silent norm. At the same time, our analysis highlighted that colour can be employed more strategically—not only as a marketing device but also as a tool for inclusivity. Used with intent, colour has the potential to destabilise stereotypes or blur binary lines that have long pigeonholed users into socially constructed gender identities. This finding aligns with recent calls for non-discriminatory design practices that critically reflect on bias and move beyond binary aesthetics (Esfahani, 2020).
The study also revealed that binary distinctions dispersed when lightness and saturation values shifted gradually within a medium range. These transitions opened a broader spectrum of gender perceptions—challenging stereotypes or erasing gender—without producing dull or lifeless aesthetics. This is particularly significant in light of concerns raised in the literature that gender-neutral products often result in bland or "numb" aesthetics (Ehrnberger, Räsänen and Ilstedt, 2012). Our findings demonstrate that vibrant chromatic combinations can emerge from intermediate HSB values that resist binary coding. Hence, colour—understood as the interplay of hue, saturation, and lightness—has the capacity either to reinforce cultural stereotypes or to subvert and reconfigure them. This dual potential underscores arguments that colour is not merely a decorative choice, but a cultural

code embedded in historical, social, and economic structures (Canlı, 2018). The central issue, then, is whether designers replicate existing codes uncritically, reinforcing imposed norms, or deliberately use colour to challenge them.

B. The implications for design

These findings have several implications for design. First, they expose the limitations of traditional gender segmentation strategies that reduce choice to the binary of pink for women and blue (or black) for men. As noted, such strategies emerged from capitalist market logic rather than innate preferences (Paoletti, 2012; Dantas et al., 2021). Today, they are increasingly misaligned with user realities, as many consumers reject gendered branding or resist stereotypical cues (Bideaux, 2022). Persisting with these strategies risks alienating diverse audiences who expect products to reflect fluid and non-normative identities. Moreover, the findings suggest that genuine neutrality cannot be achieved simply by defaulting to achromatic palettes. Black and grey tones—often paired with metallic finishes and marketed as "gender-neutral"—carry their own coded meanings and remain tied to archetypes. True neutrality must be constructed intentionally, avoiding both the masculine-as-default paradigm and the superficial use of pink accents as a form of "gender washing."

Equally important is considering colour in relation to other elements of product language. Shape, surface finish, and design details frequently overrode chromatic cues in our analysis, confirming that colour operates in tandem with form. For instance, a hand blender with gun-like ergonomics remained masculine-coded even when paired with lighter and more complex palettes, while subtle shifts in the lightness of neutral tones could move a razor across gendered zones. Such examples reinforce the view that designers often rely on generalised assumptions and personal biases rather than critically reflecting on how form and colour jointly encode gender (Stilma, 2006; McMahon and Kiernan, 2017). As observed with design students, this tendency may stem from a lack of confidence and awareness. Hence, fostering critical reflection in both design education and practice is essential. Designers must be trained not only to approach colour technically and theoretically but also to recognise the cultural, social, and historical meanings attached to chromatic choices. As argued, design based on unexamined assumptions risks producing homogeneous and exclusionary outcomes (Stilma, 2006; Canlı, 2018). By contrast, approaches that situate colour within broader socio-cultural debates can promote more inclusive practices that transcend stereotypes. The implications also extend to marketing. Product portfolios could be restructured to address diverse audiences who resist narrow, prescriptive models of gendered consumption. Instead of multiplying gender-specific variants of the same product, companies could streamline their portfolios to offer aesthetics that speak to a broader spectrum of preferences. Such strategies are not only socially responsible but also economically advantageous, reducing unnecessary duplication while expanding the user base.

C. The Colour + Gender Framework

Based on these insights, we propose the development of a *Colour + Gender Framework* as a practical tool for designers. It addresses the need for a more conscious and intentional use of colour in product design, moving beyond biased or market-driven choices that reproduce stereotypes. The framework rests on three overarching goals. First, to avoid reinforcing stereotypes by preventing colour choices constrained to binary associations of femininity and masculinity. Second, to challenge "pink marketing" and gender segregation by exposing and destabilising reductive strategies that target women through superficial chromatic coding. Third, to promote the blurring of binary dichotomies, encouraging ambiguity through colour configurations that expand the spectrum of possible identities. Together with the gender-sensitive design strategies proposed by Labarta, Ingaramo, and Mattioli (2024)—cue-free, gender-shift, and flexible design—these goals will constitute the structural layer of the framework. The framework may also integrate the analytical parameters identified in our study, which can be directly applied in practice: (i) the modulation of lightness in neutral tones; (ii)

relationships between colours—monochromy, polychromy with a dominant hue, or balanced polychromy; (iii) the interplay of saturation and lightness, with extremes reinforcing binaries and medium values fostering ambiguity; and (iv) the influence of formal language. By combining these dimensions, the framework will support designers in recognising when colour choices risk reinforcing stereotypes, experimenting with strategies that subvert or reframe them, and employing colour purposefully to create non-discriminatory outcomes.

Conclusions

This study reaffirms colour as a central and highly influential cue in the gendering of products, operating not in isolation but through the interplay of hue, saturation, and lightness alongside form and function. By analysing how these chromatic properties shape perceptions of femininity, masculinity, gender neutrality, and androgyny, the findings reveal both the persistence of stereotypes and the potential of colour to destabilise them. Importantly, neutrality cannot be equated with the absence of colour, nor can superficial adaptations of pink or blue achieve inclusivity. Instead, colour must be engaged critically and intentionally in product design. The findings provide a base for the development of a *Colour + Gender Framework*, which may offer a pathway towards more inclusive and equitable design practices, equipping designers to navigate complexity beyond binary logics.

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The emerging role of CMF designers in sustainable product development: insight from practice

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Abstract

Designers are playing an increasingly crucial role in the transition to more sustainable consumption patterns. This has opened new areas of focus in design, one of which is CMF (Colour, Material, Finish) design. CMF design allows small, low-impact changes to be made to the design of a product without disrupting the production process. Its potential benefits could be even greater if conceptualised and shared as a distinct design trajectory.
The practical and professional nature of CMF design has resulted in a lack of literature on the subject. This research aims to address this gap by exploring the professional backgrounds, training pathways, and sustainability-related perspectives of CMF practitioners.
The study is based on qualitative data gathered through interviews with 14 professionals and academics in the field. These interviews highlighted the skills and knowledge required for CMF practice and its relationship with sustainability. Finally, it was possible to identify tools for integrating CMF design with sustainability actions.
This research translates the particular know-how of a process created from the bottom up by designers into a more tangible and shareable systematisation. The findings encourage academic and professional communities to recognise CMF as a lever for innovation, with the capacity to support sustainability goals.

Keywords: CMF Design, Design Practice, Sustainable CMF.

Introduction

In the current context, the role of designers in sustainability is increasingly strategic. Designers act as mediators between the various stakeholders, becoming coordinators capable of managing the complexity of design processes in all their phases (Antonelli *et al.*, 2008). This horizontal positioning allows designers to integrate environmental and social values from the beginning of the design process, transforming sustainability into an essential design condition.
Therefore, designing with sustainability becomes part of the design process, a *conditio sine qua non*. Designers' sensitivity to sustainability (Kumar and Sarkar, 2018) allows them, through the language of objects, to educate citizens in acting responsibly towards the environment (McDonald and Oates, 2006; Wastling et al., 2018). In this sense, designers have a cultural responsibility: to engage citizens in more conscious behaviour, stimulating a systemic view of daily actions.
The multidisciplinary nature of design allows designers to have the same flexibility in their approach. Colour, Material and Finish (CMF) is an emerging and cross-disciplinary discipline among the many possibilities. Originating in the automotive tradition of the “Colour & Trim” departments, CMF design, as it is known today, began to spread in the 1980s and subsequently gained momentum in the 2000s (Zuo, 2020). By its very nature, CMF design has acquired increasing strategic importance within product development processes. This approach focuses on balancing the artefact's aesthetic and functional aspects, as well as its sensory and emotional elements (Becerra, 2016). CMF design

thus allows for the integration of sensory, cultural, technological, and, more recently, sustainable dimensions.

In the field of sustainability, selecting materials, colours, and finishes becomes part of a process that considers the entire life cycle of an artefact. From this perspective, carefully considered CMF choices can positively contribute to the broader and more complex dynamics of a product's Life Cycle Assessment (LCA).

However, the potential contribution of CMF design goes beyond material selection. This approach allows designing CMF to be easily adapted to different targets. Small changes in the product aesthetic appearance can thus make it possible to change the target while maintaining the production technologies, moulds, and materials already in use (Zuo, 2020). This flexibility opens a range of possibilities that allow companies to update themselves without incurring costs or excessive consumption.

Equally relevant is the emotional dimension that a manufactured product can generate. A product that engages all five senses satisfies the consumer's perceptual needs and emotional expectations (Becerra, 2016). The emotional experience is a fundamental aspect of consumer perception, and it is precisely these emotions, along with the emotional value associated with the perception of quality, that serve as a significant source of competitiveness.

Given its practical nature, CMF design often remains linked to professional fields. Many companies, including Philips, Nokia, and Samsung (Zuo, 2020), have dedicated sections to CMF design within their R&D departments. Despite the potential of this approach, it is still struggling to establish itself, especially in academia, partly due to the absence of a shared vision of the process or dedicated training courses (Liu, 2020). This situation limits its full exploitation, contributing to the perception of CMF as a subordinate activity compared to other established design areas.

In addition, while CMF designers frequently use established tools, these usage patterns are neither standardised nor widely shared. The existence of this ambivalence in practice has resulted in each CMF designer developing their tools, adapting existing ones to their design process. Thus, without common structures, opportunities to create new knowledge and dedicated theoretical and methodological tools are lost.

This study explores the potential of CMF design from a professional point of view. It aims to understand how this approach can effectively promote sustainability. While literature references the selection of colours, materials, and finishes from an LCA perspective, there is limited understanding of how such practices are integrated into professionals' everyday work.

By adopting a qualitative approach, this research pursues a twofold objective. First, the authors aim to bridge the gap between theoretical reflection and applied practice, providing valuable insights for defining an operational framework for sustainable CMF. Second, the study seeks to understand how professionals perceive and address the issue of sustainability in their daily work.

Therefore, the research question is: *how can CMF be a concrete lever for integrating sustainability into design processes, and what opportunities do CMF designers perceive?*

The evidence presented in the following sections offers both academics and practitioners an initial basis for fostering greater critical awareness and advancing the integration of sustainability within CMF practice.

Methodology

This research is part of a broader doctoral project investigating how CMF design can be used as a lever in sustainable design, particularly in conveying sustainable behaviour. For this reason, the study presented here is part of a Grounded Theory framework.

Grounded Theory is a qualitative methodology to social research developed by Glaser and Strauss (1967) to bridge the gap between theory and empirical research. Unlike other approaches, it does not start from predefined hypotheses but constructs theories directly from data collected in the field. This

process involves a continuous alternation between data collection and analysis to bring out concepts and categories consistent with the participants' lived experience. The nature of the topic reinforces the appropriateness of Grounded Theory, which is particularly suited to exploring areas that are under-studied or where knowledge is still limited (Payne, 2007).
Within this framework, interviews play a central role. Semi-structured interviews were conducted with CMF design professionals to explore their experiences, meanings, and professional contexts.
Respondents were selected according to the professional profiles identified in Liliana Becerra's CMF model (2016): colour design, colour development, material design, material development, surface design, finish design, CMF strategy, CMF development, trend tracking and forecasting, storytelling, and marketing. The professional profiles were then cross-referenced with various possibilities, such as professional roles and operating contexts, including freelance, studio consulting, company (R&D department), and academia. The interviewees' selection was targeted, starting from publicly available information on personal or company websites, to ensure representativeness concerning the diversity of roles in the contemporary CMF landscape.
The interviews, which lasted approximately 45 minutes, were conducted in person and online, with the assistance of question slides on PowerPoint. The research protocol was approved by the Politecnico di Milano Ethics Committee, and all participants signed an informed consent form, authorising the use of the data collected and its processing per current privacy legislation.
The discussion followed a flexible structure organised around three main themes: training and background, professional practices, and integration of sustainability into design processes. The goal was to obtain meaningful data from the professional field and experiences that will allow the authors to understand design processes and specific knowledge about the vision of sustainability.
All interviews were audio recorded, transcribed, and coded using MAXQDA software. The main tools of Grounded Theory include *coding* - assigning labels to text segments to summarise their meaning - and *memoing* - reflective writing used to record insights and theoretical connections (Saldaña, 2013). Through the coding process, it was possible to obtain 22 code categories. These codes were then compared and aggregated to identify significant recurrences, divergences, and trends within the text corpus. The results, presented in the following section, highlight actions that illuminate the main challenges and opportunities for embedding sustainability in CMF practices.

Results and discussion
The results of the interviews were analysed according to the 22 codes. Specifically, as can be seen from the graph (Fig. 1), the code that received the most responses concerned sustainability strategies, followed by the relation of CMF with sustainability in general.

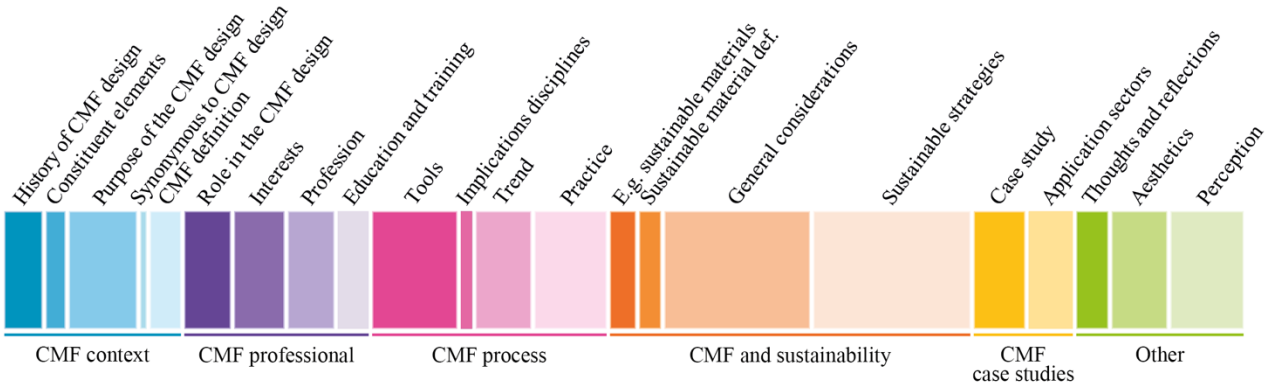

Fig. 1 - Graph showing the codes identified and analysed, divided into categories. The width of each rectangle is proportional to the number of elements selected for that code. Image by the authors.

Moreover, thanks to the interviews, it was possible to clarify points regarding the CMF process, according to the most recurring group of codes. They further revealed significant insights regarding

the tools used, different perspectives on trends, and some measures implemented in practice. Third and fourth place were occupied by information about professionals and the context of CMF design. The authors decided to keep track of considerations regarding aesthetics and perception for broadening the leading doctoral research.
Starting from the characteristics of the interviewees, the figure of the CMF designer has a background linked above all to design and architecture. The interviewees' training is mainly related to product or graphic design, with a few exceptions in architecture. This is primarily linked to the relatively recent emergence of Product Design courses, which have led to greater specificity in training.
The interviewees' profiles are mostly professional, with only five interviewees working exclusively in academic research. However, seven combined professional practice with teaching activities within university courses. As Table 1 shows, the respondents identified themselves in multiple roles (Becerra, 2016), completing almost the entire matrix.

CMF role specialisations	Freelance	Studio consulting	Company (R&D)	Academic
Colour design	X	X	X	X
Colour development	X	X	X	X
Material Design	X	X		X
Material Development	X	X		X
Surface Design		X	X	X
Finish Design	X	X	X	X
CMF Strategy	X	X	X	X
CMF Development	X	X	X	X
Trend tracking and forecasting	X	X	X	X
Storytelling and Marketing	X	X	X	X

Tab. 1 - Matrix showing the roles and professions with which respondents identify themselves.

Although Liliana Becerra's book (2016) was intended to systematise CMF, not all professionals always agreed upon this proposed division of roles. Given the fluid and permeable nature of CMF design, many found it challenging to identify with the different categories, mainly because they did not see them as separate/separable entities.
The interviews also revealed different ways of defining or labelling CMF design. CMF is also spelled CFM. Other terms in use include surface design and soft design. Despite this terminological diversity, almost all respondents agreed that the CMF aims to design the experience as intangible and linked to emotional identity. In this sense, both functional and emotional attributes contribute to identity, making CMF akin to *"dressing the object"* – understood as an artefact of different natures – by defining its skin and outermost layer. CMF design thus becomes a "bridge" between the designer's conceptualisations and the intended message for the user. The three components of colours, materials, and finishes are not separable; they have elements in common and influence each other. In this context, CMF design becomes an area of application that makes colour practical, moving towards a more concrete relationship with materiality. The product is seen metaphorically as "grey clay", with the CMF design completing the functional and aesthetic aspects. Professionals see aesthetics as the external appearance, the way an artefact presents itself. Consequently, since aesthetics is linked to external appearance and the latter is closely connected to identity, CMF design allows for identity design, and aesthetics are closely related.

The broader purpose of CMF design is to create a visual language that conveys messages. These messages can be of various kinds, from the more practical ones related to the function and affordance of a product (e.g., texture/grip) to brand communication. The latter, closely related to marketing, helps companies strengthen their brand identity and customer loyalty. It connects the user and the artefact, creating desirability and added value through experience and emotion. Importantly, the messages communicated are also linked to sustainability.

The interviews revealed several considerations regarding the relationship between CMF and sustainability. Initially, within the evolution of sustainability as a megatrend and design driver, there was a period in which CMF was exclusively a trend. Sustainability was not a prerequisite but rather an alternative proposition. Today, however, it has become fundamental and enters the process right from the brief. From the interviews, several visions have emerged that allow us to create a list of seven actions CMF design can take to assert its role in sustainable design:

1. CMF to communicate sustainability
2. CMF to cultivate a sustainable culture
3. CMF to ensure visual sustainability
4. CMF to last over time
5. CMF to build inclusive languages
6. CMF to create synaesthetic harmonies
7. CMF to reduce impact

CMF to communicate sustainability. CMF can lead to building the perception of the sustainability of artefacts differently, working on the more aesthetic aspects. The most intuitive approach is to use a transparent material language, thus making the eco-credentials behind an artefact visible. This is linked to specific material, colour, and finish characteristics with irregularities and visible inclusions, thereby promoting new aesthetics for products made from innovative materials. When employed effectively, this kind of language facilitates the identification of the components or the life cycle of the artefact itself as sustainable.

However, this is not always possible. Sometimes, characteristics are deliberately concealed due to aesthetic incompatibility or conceptual ideals. In such cases, the sustainability communication can be achieved using labels or certifications that elucidate the underlying choices.

A more critical issue concerns using “fakes” – such as fake wood or fake marble. Two distinct positions emerged. Some interviewees are against using these materials, as faithful imitation of colours and textures can mislead the end user. This happens not only when the product is discarded, but also from a more sensory point of view. Thus, there is no correspondence between the perception of the different senses: when touched, a table resembling wood reveals its true nature as plastic. On the other hand, supporters of fakes say that if you focus on perception, it doesn't matter if the material is wood or not, because you're working on emotion. Consequently, this could lead to environmental benefits, especially when considering using certain types of wood or stone.

Mediating between these visions is the prospect of developing new aesthetics, building on less impactful choices, even without an agreed-upon aesthetic. Thus, it is possible to work on abstract concepts to propose new possibilities that may connect with tradition while pointing toward the future.

CMF to cultivate a sustainable culture. Linked to the materials language, new materials have established dynamics whereby imperfection, irregularity, and inclusions are sustainability indicators. Although these aspects are becoming increasingly popular and evolving into new, more synaesthetic models, some people are not yet ready to accept imperfection.

Imperfection is not always stable due to irregularities, but it can also be linked to the evolution of the material over time. Therefore, it is essential to leverage that this is not a “malfunction” but a *plus* that creates uniqueness. It is thus a question of consciously informing the consumer so that transformation

also becomes added value, something unique. Accepting irregularities, pastel colours, etc., is also part of a cultural process of receiving this new aesthetics. Processes are needed to educate new consumers to make choices that go beyond the pursuit of perfection and to accept the language change that is taking place.

CMF to ensure visual sustainability. A deeper analysis of the purpose of CMF design reveals that it is not only about designing the artefact as a stand-alone entity, but also about its relationship with other objects, integrating seamlessly into different contexts. Therefore, designers start by considering the environment, which must be less chromatically polluted, so it does not overload the user's perception. Moreover, fitting artefacts into existing environments allows designers to work on the project's identity. The main objectives become adaptability and timelessness, allowing the product to function in many different contexts. So, the sustainability paradigm is changing. Previously, the search was for objects with an iconic character; now, adaptable artefacts are needed, with a lengthy visual life span equal to their physical one. Linked to this aspect is the request for timeless colour. It is necessary to focus on colour schemes consisting of a few colours that can be easily adapted.

CMF to last over time. From the previous action, the thought expands to become "durability over time". This gives rise to the theme of lasting identity from all points of view. It is not just a matter of responding to an ideal or integrating visually into the context; it becomes an increasingly objective and universal language. This is where the most functional part of CMF design comes in, balancing aesthetics to find its dimension. Selecting and defining colours, materials, and finishes that consider the product's life cycle leads to an evolution in interaction. Users may then accept gradual changes in appearance or interaction as natural. This objective is realised in the design of new materials, which must still be capable of guaranteeing the performance, aesthetic colour, and finish of traditional materials to be accepted. The theme of timelessness, emphasised by university professionals, is increasingly becoming a guiding trajectory, even among younger designers.

CMF to build inclusive languages. CMF is also responsible for fostering inclusivity, considering diverse sensory and perceptual needs. For designers, this means carefully evaluating their choices from a social point of view, opting for colours, materials, and processes that do not involve forms of exploitation and that promote accessibility. Inclusive language can translate, for example, into design solutions for children and older people or people with colour blindness, facilitating their interaction; or into systems that elevate CMF to a proper communication tool for blind people or those with severe medical conditions. Conversely, fake materials may mislead users who rely on touch, suggesting a surface is natural when it is not. More broadly, with a view to social sustainability and the involvement of all stakeholders, there is an opportunity to integrate inclusion as a guiding principle in co-design processes, especially in larger-scale projects.

CMF to create synaesthetic harmonies. CMF design can become a key tool for creating new synaesthetic harmonies with a view to sustainability. Working on innovative finishes allows us to modify the perception of colours and broaden the spectrum of interaction, giving rise to new visual effects, such as colours that change with light or appear different from different perspectives. Design synesthesia engages multiple senses simultaneously: textures that evoke sounds, surfaces that stimulate touch, and colours that generate emotions. Such strategies compensate for limitations of new sustainable materials, integrating them with solutions that arouse curiosity and offer familiarity, strengthening the link with already known sensory experiences. This aesthetic-sensory research not only innovates the product's visual and tactile language but also contributes to a more empathetic and lasting relationship between the user and the object, promoting more conscious and responsible consumption.

CMF to reduce impact. The concept of reduction in CMF design can be addressed on several levels. Starting with the most immediate aspect, it is possible to intervene in the quantity of material used, choosing lightweight solutions with a good balance between strength and weight, thus reducing the impact of transport. During production, waste can be minimised by adopting processing and finishing

technologies that optimise the use of resources. A further reduction can be achieved in the colour palette: more essential colour charts allow for less waste, avoid overproduction, and keep customisation as a targeted exception. From a more systemic perspective, finishes and textures can offer aesthetic variations without significantly impacting costs or the environment. On a larger scale, reduction can also be achieved by choosing materials with a low ecological footprint or sourced locally, thereby enhancing local resources. Finally, designing with flexible and upgradeable systems in mind allows for easy adaptation to new scenarios, textures, and targets, extending the product life cycle.

Tools and Approaches for Sustainable CMF Design.

CMF design can be guided sustainably using conceptual and practical approaches.

Starting with the conceptual tools, storytelling plays a key role. Storytelling makes the project's value easier to communicate by showing the sustainability principles that underpin it. As shown above, communicating a project's sustainability is a fundamental step. Reflection can focus on cultural and emotional elements linked to the analysis of perceived value. In this way, targeted storytelling opens a communication channel between companies, designers, and users.

Participatory and exploratory methodologies represent another potential source of inspiration. Among these, fictional design and future scenarios enable preparation for tomorrow’s contexts, anticipating sustainable and innovative solutions.

Turning to more practical tools, moodboards are indispensable in CMF design. A moodboard translates the designer's vision into something more tangible, with design directions that capture the sensibilities of both the end user and the company. The next step is the creation of maps that allow colours and materials to be designed and organised by hue, lightness, saturation, or according to geographical, sensory, and sustainability parameters. Diagrams and charts visualise the proportions and quantities of colours, materials, and finishes, while the material box or material-board offers concrete samples for tactile and aesthetic evaluation. Through the materials panel, designers can give concrete form to innovation, communicating and allowing people to experience new possibilities. This can lead to more inspirational proposals, such as those related to new materials and more technical ones related to specific processes, such as powder or water-based paints.

Finally, a tool currently viewed by professionals as somewhat controversial is the trend. Trends are defined as changes in society or specific groups, ranging from profound transformations to ephemeral phenomena. In sustainable design, trend research and forecasting help identify new aesthetics, innovative materials, and solutions that might not otherwise be considered, facilitating positive environmental impact and market adoption. However, the global trend system is often unbalanced: trends emerge in specific contexts (mainly Europe and the United States) and spread elsewhere, with little attention to local values. Furthermore, their original goal – to reconnect with people and intercept their needs and emotions – has been partly lost, replaced by marketing logic that pushes for rapid consumption. This leads people to follow trends for no real reason, intoxicated by their appeal, without fully understanding their real needs. Nevertheless, trends still hold potential. Used ethically and inclusively, they can foster the creation of lasting products. This could mean trends that do not create addiction but encourage dialogue and culture, visualising tools and opportunities for interaction that raise user awareness.

Despite the wide range of possibilities CMF design offers regarding sustainability, several difficulties remain that slow down its effectiveness. For designers, keeping up with sustainable criteria means constantly monitoring the entire production process. Still, there is a lack of standardised tools and shared control systems. The absence of a shared vision frequently results in the inability of companies to network. Better coordination would facilitate knowledge sharing and improve new materials' performance and aesthetic results, allowing for more informed choices. Other significant obstacles

are related to the risk of greenwashing and the high costs of new materials or technologies. In this context, the path towards truly sustainable CMF design requires innovation, collaboration, transparency, and economic strategies that ensure financial viability.

Conclusion

By gathering different approaches, this study reveals recurring themes, key tools, and mindset elements that characterise CMF design when it aims to contribute to sustainability.

The role of the CMF designer, given its multidisciplinary nature, is particularly relevant in transition contexts. However, designers must step outside their comfort zone (Manzini, 2009). They must learn to work under conditions of uncertainty, acquire new skills, explore different disciplinary languages, and engage in dialogue with experts from various fields (Micheli et al., 2017). This ability to cross boundaries and connect knowledge is essential to drive profound change. Designers are no longer simply creators of objects, but facilitators, connectors between disciplines, social actors, and interpreters of complex scenarios. CMF designers also fit into this context, not only by having a vision of the supply chain, but also by designing the various interactions from above. For this reason, design can only make a concrete contribution to the ecological transition if it can operate at multiple levels.

In addition to guiding aesthetic and functionality, CMF offers concrete possibilities for sustainable innovation: from the selection of low environmental impact materials to designing for durability and creating finishes and colours that reduce waste and promote reuse and disassembly.

The future trajectories for CMF design certainly open the possibility of exploring the ethical dimension in greater depth. In this sense, adopting synesthetic approaches and inclusive languages allows the development of products accessible to a broader audience, enhancing the sensory experience. Furthermore, integration of digital and physical strategies has the potential to yield additional scenarios, facilitating exploration of novel interactions between physical materials and digital experiences. This, in turn, optimises resources and expands the possibilities for customisation without generating waste. In this context, CMF becomes a strategic tool that guides informed choices and transforms design into a fundamental driver of change, where aesthetics, functionality, and ethics intertwine to build sustainable and innovative products and systems.

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Capsule collection.
A tribute to the chromatic and geometric depth of Josef Albers

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Abstract

The capsule collection, a thesis in Fashion Design from the Bachelor's Degree Program in Industrial Design at the Department of Architecture, University of Florence (2023), explores colour as a core element of fashion design, inspired by Homage to the Square (1952). The palette of green, black, light blue, and white acts as both a visual code and a design tool, creating bold contrasts and chromatic inclusivity. Matte, iridescent, and translucent fabrics enhance the perceptual experience. Aimed at active, urban women, the collection blends functionality, modularity, and refinement. Rational construction meets deconstructed forms, turning the body into a living design surface.

Keywords: colour as language, colour and emotional engagement, art and fashion design, Homage to the Square, Square Advancing Spring

Introduction

In the fashion sector, colour assumes a multifaceted role that transcends its purely aesthetic function, encompassing emotional, cultural, and commercial dimensions (Kauppinen-Räisänen & Luomala, 2010). Its deployment exerts a significant influence on the construction of both individual and collective identities, while concurrently shaping the perception of brand value and informing strategies for sustainable innovation (Chevalier & Mazzalovo, 2012). Research in colour psychology has demonstrated that chromatic choices modulate consumer behaviour and emotional responses, thereby fostering deeper engagement and personal identification (Elliot & Maier, 2014). Within the context of fashion design, the deliberate and informed management of colour facilitates the integration of functional, aesthetic, and symbolic dimensions, enhancing the communicative efficacy of the product and its capacity to respond to contemporary imperatives of sustainability and innovation (Kumar et al., 2021). Accordingly, proficiency in colour constitutes a pivotal competency for the collections development that faithfully reflect the evolving dynamics of contemporary fashion system (Fig. 1).

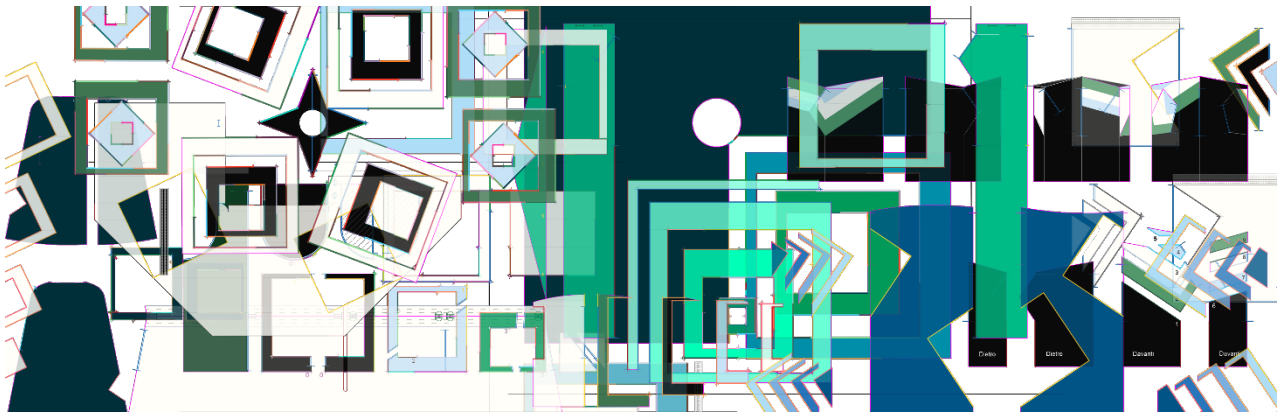

Fig. 1 - Concept board of the patterns for the capsule collection:
Ars Combinatoria and Metamorphosis. Advancing Spring (by author, 2023)

Design Context of the Collection

The proposed capsule collection, "spring over 35", is positioned in line with current market dynamics, responding to three central demands: versatility, sustainability, and personal identity. The project

adopts a hybrid, conceptually dense format, capable of combining production efficiency with a drive towards formal and material experimentation.

The analysis focuses on the relationship between art and fashion, historically characterised by a dialectic oscillating between contamination and separation: "fashion and art are not isolated realms, but semiotic fields that intersect and mutually redefine one another" (Calefato, 2007, p. 18).

In contemporary contexts, this relationship assumes unprecedented forms of convergence, expressed through a network of fluid and multidirectional exchanges. Thus, it moves beyond mere aesthetic contamination and the dichotomy inherent in traditional definitions of art and design, opening up more complex interpretative perspectives. Within this framework, art and fashion emerge as complementary agents in the symbolic production of today's visual culture (Rocamora & Smelik, 2016).

Art contributes to fashion by providing conceptual depth, linguistic autonomy, and an experimental vocation; fashion, in turn, offers art materiality, function, and social temporality. In the specific case of this capsule, the artistic reference does not merely serve as a decorative citation but rather functions as an epistemological matrix. Textile surfaces are developed through abstract visual logics, perceptual processes, and modular structures, with direct references to modernist painting. As Kawamura observes, "fashion is an institutional system that produces and regulates meanings, beyond the material object" (2005, p. 3). The result is an open visual system in which the garment serves as both an aesthetic medium and a semiotic device, capable of evoking symbolic universes rather than directly representing them.

The target audience is thirty-something women who are active, urban, and digitally connected—representative of a demographic segment that is increasingly strategic for contemporary brands. The design approach is grounded in the integration of functionality, aesthetic quality, and identity values (Brun, 2021), with particular attention to the social and environmental awareness that characterises younger, culturally informed consumers (Joy et al., 2012).

Josef Albers: Colour as Language and Compositional Structure

The central theme of the collection is a tribute to Josef Albers, artist and theorist of colour, whose research focused on the perceptual relativity of colour and its capacity to generate spatiality and depth through rigorous contrasts and combinations.

Josef Albers (Bottrop, 1888 – New Haven, 1976) represents a pivotal figure in the transmission of European modernist thought to the United States, not only for his artistic contribution but above all for the development of an innovative pedagogy grounded in perceptual experience and formal experimentation. Trained within the industrial context of the Rhineland and initially active as a primary school teacher, Albers entered the Bauhaus in Weimar in 1920, where he distinguished himself through a radically experimental approach to the use of humble and recycled materials—such as glass, metal, and paper—integrating art, craft, and function (Droste, 2006).

At the Bauhaus, he attended Johannes Itten's courses, assimilating a synaesthetic method based on the relationship between colour, form, and perception, and was appointed as an instructor as early as 1922. With the school's relocation to Dessau in 1925, Albers assumed a central role in both directing the stained-glass workshop and teaching the Vorkurs, the preliminary course designed to develop the foundations of visual and design sensitivity. Within this context, he collaborated with leading figures such as Paul Klee and Wassily Kandinsky, contributing to an artistic education which, in line with Walter Gropius's vision, sought to transcend traditional hierarchies between applied and fine arts, promoting unity between the creative process, function, and the social dimension (Wick, 2000).

Albers's pedagogical approach was rooted in the principle of learning by doing, enhancing the manual and sensory intelligence of students through exercises involving the manipulation of simple materials (wire, paper, raw wood), studies of visual perception, and explorations of the relationship between figure and ground, light and colour. His method privileged process over final product, encouraging students to adopt a design-oriented mode of thinking, the conscious use of error, and intuition and surprise as cognitive tools within artistic practice (Forgács, 2016).

With the forced closure of the Bauhaus in 1933 under Nazi repression, Josef and Anni Albers emigrated to the United States, aided by the intercession of Philip Johnson, curator at MoMA. In America, Albers became the first director of the visual arts programme at Black Mountain College, an experimental institution in North Carolina inspired by the progressive pedagogical philosophy of John Dewey, according to which artistic learning should derive from direct experience rather than imitation (Dewey, 1934; Horowitz, 2014).

Within the Black Mountain College, Albers developed a teaching method based on analytical observation, the use of the non-dominant hand, optical deconstruction, and the employment of negative space. These formative principles profoundly influenced a generation of artists, including Robert Rauschenberg, Cy Twombly, Susan Weil, Ray Johnson, and Eva Hesse, who inherited his focus on formal reduction, chromatic interaction, and the open semantics of the artwork (Sikkema, 2003).

Fig. 2 – Joseph Albers: Homage to the square. Advancing Spring right bottom.
The collection 'Ars Combinatoria and Metamorphosis' pays homage to 'The Square Advancing Spring'.

In 1950, Albers was invited to lead the newly established Department of Design at Yale University, where he continued his theoretical research on colour and initiated the celebrated pictorial series Homage to the Square (1950–1976), a systematic investigation into the perceptual effects of chromatic relationships on flat surfaces. (Fig. 2)

His sustained research constituted a visual and conceptual laboratory in which colour was not studied as an absolute entity but as a subjective and relational perceptual experience. Albers argued that colour is "the most relative medium in art" (Albers, 1963), since it changes according to context, thereby challenging traditional objective notions of chromatics. To analyse and systematically compare these chromatic phenomena, Albers employed the geometric rigour of the square—a rational, modular figure that functioned as a methodological tool to isolate chromatic interactions and deepen the understanding of visual perception.

Homage to the Square is among the longest, most coherent, and methodical pictorial cycles of the twentieth century, comprising approximately 2,000 variations across paintings, prints, and studies, many of which are now held in museums and private collections worldwide. Each work is composed of three or four concentric squares painted by hand, with apparent simplicity yet meticulous attention to tonal variation, saturation, and the perception of depth. The strict geometry enables a direct reading of chromatic instability, generating optical illusions of expansion, contraction, and vibration-anticipating later explorations in Op art and visual computation (Anuszkiewicz, 1975; Gage, 1999).

Numerous studies in the field of perceptual psychology have subsequently confirmed Albers's intuition: the perception of colour is a cognitive construction influenced by contextual, luminous, and cultural factors (Elliot & Maier, 2014; Valdez & Mehrabian, 1994).

During this same period, Albers produced his most influential theoretical work, Interaction of Colour (1963), which stands as a manifesto of twentieth-century visual pedagogy. Structured as an experiential atlas, the volume proposes a didactic model based on active observation, learning through practice, and utilising error as a cognitive and formative resource (Albers, 1963).

Even after his retirement from Yale, Albers continued his artistic activity, receiving significant public commissions, including murals for buildings in New York and Harvard. His legacy does not reside solely in geometric abstraction or colour pedagogy: his most radical innovation lies in having conceived the school as a perceptual laboratory, where the act of seeing precedes and grounds all forms of artistic knowledge. Within this perspective, vision becomes the ultimate aim of the educational process, anticipating epistemological sensibilities that remain relevant in the twenty-first century.

To this day, theoretical, critical, and design-oriented re-elaborations of his thought continue to unfold across the fields of art, design, perceptual psychology, and digital visual culture. Contemporary art critics and theorists have re-evaluated Albers's systematic approach as a form of conceptual minimalism, in which repetition and variation are not merely stylistic devices but epistemological strategies. Recent exhibitions and publications (Tate Modern, 2018; Guggenheim, 2019) have highlighted the political and cultural significance of his work, particularly its insistence on the relativity of perception-a theme now central to information design and digital visual cultures.

Finally, the digitalisation of chromatic experience has introduced new tools for analysing and simulating the effects described by Albers. Visual processing software and augmented reality have been employed to recreate in virtual environments the perceptual variations explored in the Homage to the Square cycle (Lee, 2022).

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Albers's legacy can be traced across multiple contemporary domains.

Fig. 3 - Hommage au Carré, a limited edition of scarves paying tribute to Josef Albers, designed for the first edition of Hermès Éditeur

In conceptual art, colour as a coding system finds its roots in the Albersian method, as demonstrated by artists such as Ellsworth Kelly, Bridget Riley, and Sol LeWitt.

In the academic sphere, Albers's pedagogy of colour remains highly relevant: numerous schools of art and design continue to adopt an experiential and phenomenological approach to chromatic study, in line with theories of perception-based design (Wong, 1997).

In graphic and interactive design, the interplay between colour and context constitutes the foundation of visual interfaces and user experience (Lidwell, Holden & Butler, 2010).

In fashion and textile design, Albers's geometric and chromatic constructions have inspired serial patterns, chromatically modulable capsule collections, and the development of colour as a design grammar (Black, 2012).

In 2006, for the inaugural edition of Hermès Éditeur, Hermès chose to collaborate with the Josef and Anni Albers Foundation, producing Hommage au Carré, a reproduction of six works on silk, each issued in a limited edition of 200. The decision to open the series with Albers was deliberate, as articulated by Pierre-Alexis Dumas, Artistic Director of Hermès: "His works are profound reservoirs of sensations and emotions that seize us even when we do not fully understand them. … These six scarves by Josef Albers, or squares of silk, pushed us to the very limits of our savoir-faire." (Hermès, 2006).

Further capsule collections inspired by Albers's Homage to the Square series, and realised in collaboration with the Josef & Anni Albers Foundation, include Roksanda Ilinic (2013), Vestige – Capsule Collection (2021), and Loewe x Albers – Ready-to-Wear & Accessories (Autumn/Winter 2025).

Contrast, Layering and Chromatic Inclusivity

The adopted colour palette - green, black, light blue, and white - derives from the work "Advancing Spring" (1952), part of the "Homage to the Square" series. This does not constitute a literal citation, but rather a conceptual re-elaboration, whereby colour becomes not only a visual tool but also a communicative and narrative medium.

The use of symbolic colours such as black and white reinforces the construction of the collection's visual identity. These two extremes act as semantic anchors: black conveys authority, essentiality, and introspection, while white suggests openness, luminosity, and potential. Together they generate a modern, recognisable, and coherent aesthetic, suitable for modularity and for the construction of a distinctive visual language (Eiseman, 2017).

The palette allows for a wide range of tonal combinations and visual layering, ensuring the garments' trans-seasonal wearability. This aspect acquires strategic significance, both practically and communicatively: it enables the creation of outfits that can adapt across seasons without appearing out of context, while simultaneously responding to the requirements of an essential, modular, and evolving wardrobe. Variations between light and dark tonalities across the garments further enhance chromatic inclusivity, fostering greater adaptability to diverse skin tones and stylistic preferences

Fig. 4 - Capsule collection: Hars Combinatoria and Metamorphosis. Advancing Spring (by the author, 2023)

Fabrics, Materiality, and the Phenomenology of Colour

A particularly innovative element of the project lies in the use of colour as material rather than merely as surface. The selection of opaque, translucent, or iridescent fabrics creates dynamic optical effects, transforming the garment into a mutable phenomenological field. This approach resonates clearly with Albers's conception that "colour is the most relative medium in art", to be understood as a visual experience in constant flux, contingent upon light, context, and subjective perception.

The use of these materials is not confined to a decorative purpose but amplifies the chromatic and sensorial depth of the project. The collection thus embraces an experiential approach, in which the relationship between material and colour is lived rather than simply observed.

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Geometry, Construction, and Design Freedom

From a morphological perspective, the collection employs a rational logic in garment construction, while simultaneously opening itself up to design contingencies and geometric deconstruction. The inspiration drawn from Albers's square surfaces is articulated in the transformation of planar geometries into volumes and in the superimposition of geometric structures, generating new forms and meanings.

The garment is thus conceived as a dynamic composition, in which the body becomes an active component of the work: a mobile, three-dimensional canvas. The notion that "Art is not an object, art is an experience" (Albers, 1971) is here transposed into fashion design, where the garment ceases to be a mere aesthetic object and instead becomes an experiential device and performative act.

Fig. 4 - Forty possible combinations and transformations of the garments from the capsule Hars Combinatoria and Metamorphosis. Advancing Spring (by author, 2023)

Conclusions

The capsule collection, grounded in three design pillars-namely, the transliteration of art, accidental cutting, and transformative wear-distinguishes itself through its capacity to translate a complex artistic language into a fashion proposal that is functional, sophisticated, and profoundly aligned with the demands of contemporary times.

The square, both as a symbolic figure and a structural module, serves as the generative principle of the collection, manifesting in its patterns. In the garments themselves, Advancing Spring (1952), with its perceptual dynamism, appears either as a direct citation of the work or as a wholly reinterpreted and deconstructed form through the creation of soft, dynamic three-dimensional volumes.

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Color design for public space

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Abstract

Color can be the core element to create specific environment of the city. Color has important role in perception of the city, not only the huge dimensional application such as urban planning and architectures but also small public spaces. Today, our cities are continually privatized, public spaces can play a vital role in ensuring that citizens can freely reside and enjoy equal quality of life. Public space can be an important hub for aggregation of residence and the visitors of the city. Well-designed public space permits to moment for repose and break time for local urban areas to link more people to communicate together, and color design contributes for this.

This project demonstrates the importance of color design role in public space, how can public space from anonymous space to convert a visually pleasant public space, where the people spend time. Artistic approach to place-based color design makes aesthetically improved features to the public space, indeed can contribute to create placemaking to give more possibility for community. In collaboration with non-profit organizations composed of volunteers for the realization of the urban regeneration project with color design of a degraded urban space can be the concrete solution for the city. Color design is the most appropriate and useful way to enhance public space by providing aesthetics and communication of space quickly and economically. While murals contribute to street art as the artist's personal work, color design for public spaces can encourage citizen participation and contribute to forming a local identity while also building the identity of the city itself through research into colors and shapes appropriate for each location.

Keywords: Color design, Urban space color design, Color place-making, public space color design,

Introduction

Color is one of the most important influential factors for our well-being and psychological wellness. We live in an urban area often its materials and colors are mostly similar than others, not only because of industrialization of building fields tend to construct buildings with similar finishings, but because of lack of creative and color plan for them. Same as buildings, which are most dominant subjects visibly in urban context, from small dimension urban space to big urban areas of cities are lack of their identity and recognizable aspects. This paper demonstrates the possibility to enhance this urban problem with site specific projects especially urban spaces, where the local residences and visitors could enjoy identified and more harmonious urban areas through realized color projects, which the author is project director. Especially near schools where the family and local residences are involved, or community center where communication among users could create positive future for the city.

(Fig.1 Giardino B.Munari a Milano).

Color role in urban context

[The lack of diversity and vitality unwittingly hinders the presence of people in space and their participation in civil life. By considering this, making diversity and creating joy is an appropriate space and easy possibility. The most striking example is the commercial streets and children's playgrounds and their color variation. In order to create happy spaces, it has become obvious order.] [1]

The City of Milan has developed an innovative program for the regeneration and enhancement of public spaces, called [Open Squares][2]. The project, promoted by the City of Milan and developed with AMAT - Agency for Mobility, Environment and Territory, in collaboration with Bloomberg Associates and the Global Designing Cities Initiative, aims to pursue the urban regeneration and sustainable mobility objectives of the Milan 2030 Land Management Plan and the Sustainable Urban Mobility Plan, as part of the Neighborhood Plan. Open Squares aims to enhance public spaces such as gathering places at the heart of neighborhoods, expanding pedestrian areas and color intervention and promoting sustainable forms of mobility that benefit the environment and the quality of life in the city.

In collaboration with WAU! Milan (an acronym for We Are Urban), a volunteer organization that aims to improve the quality of life through urban redevelopment and enhancement projects, actively involving those who live there every day, main partner of Open Square Milan project, I and our team Magma project created several interventions of color design for Milan city.

Color design for public space

01. B.Munari garden in Milan municipality 8

The first project is for Munari garden located in Milan Municipality 8, sustainable and colorful redevelopment of urban space. The garden in Via Toce near primary school B.Munari, long vandalized and neglected, has come back to life with the sole use of color that, beyond aesthetically redeveloping the degraded area, adopted green urban planning interventions. We used special paints with anti-smog nanotechnologies capable of reducing pollution density by 89% (equal to the activity of a 300sqm wooded area). Therefore, the redevelopment not only made the garden more pleasant and creative but also improved the air quality of the surrounding area.

[Color composition as one of the most effective factors on color perspective is term that two or more colors in a way put together have a special order and give a special meaning. Selecting the tone, their ratio and state, pitch place, their direct, the relation

Fig.2
From existing color analysis surrounded urban context, I picked 5 colors to apply. We used anti-smog paint to make this project as a part of green urbanism. Graphic composition and words inspired by Bruno Munari's vision. This design permit to remember important designer and theorist B.Munari and harmony with its context at the same time, became pleasant point of aggregation of this urban area instead vandalized and ugly wall.
Foto Courtesy by Magma project, ph Mirko C.

[1]Pakzad, J. The city's image of what Quinn Lynch understands, Journal of Urban Planning and Architecture, Number 25-53, 20.2007.

[2] https://www.comune.milano.it/aree-tematiche/quartieri/piano-quartieri/piazze-aperte

of colors together and finally, each of the seven contrasting colors, are effective factors to create color combinations][1].

Fig.3_Left_before intervention, back side of playground and benches.
Fig.4 _Right_after color intervention, creating color trees, which could see or unseen changing seasons and existing trees.
Foto Courtesy by Magma project, ph Mirko C.

The chromatic interventions recreated different environments within the garden: a corner wall has been transformed into an area dedicated to children, a series of painted trunks form a sort of "trees behind trees" labyrinth, a service shed became the canvas for an abstract urban landscape, and a network of air conductor turned into a colorful urban sculpture. The activity was commissioned by Association WAU! Milano and created with the support of the Maurizio Fragiacomo Foundation.
We made 4 color design projects in this area: first is the mail wall on the corner of via Toce, dedicated to B.Munari's composition idea and his vision for education with 5 primary colors in link with surroundings. Second is trees with colors located in backside of playground and benches, totally abandoned area. We cleaned and systemized all the area with volunteers from WAU! Milano, and colored geometric tree shapes with 4 tons of green to enhance existing trees and potential interest in this area.

Fig.5 _Left_ cube shape structure for exit of underground parking. Previously abandoned and totally covered with unplanned doodles.
Fig.6_Right_Air conductor for underground parking. Previously totally covered with unplanned graffiti .
Foto Courtesy by Magma project, ph Mirko C.

[1] Ethan, J, coloring book, translated by Mohammad Hossain Halimi, Tehran, Printing and Publishing ministry of Culture and Islamic Guidance, Second Edition, 1988.

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Color design for public space

02. Via D.Giucciardi near M.Curie primary school Milan municipality 9

The second project is near Marie Curie School, the use of color graphically recalls the scientific instruments used by Polish physicist, chemist, and mathematician Marie Curie, a double Nobel Prize winner in the early 20th century, after whom the school on Via Guicciardi is named. As with the Bruno Munari Gardens, color plays a significant role here, used as an effective and rapid tool of soft urbanism, aiming to radically transform the perspective on a sadly degraded area of the city. The event, supported not only by the WAU Milano association, but also by two major Italian brands (a bank and a high fashion brand), who took the opportunity to create some truly unique team building activities

Fig.7_Wall in front of primary school M.Curie Foto Courtesy by Magma project, ph E.Zamponi

Via Giuicciardi, locate in Milan municipality 9 in front of Primary school M. Curie. Nonetheless this street is near kindergarten and primary school, the street was vandalized, and walls were cracked. Cultural and educational aspects for this project derived from the dedication of color and graphic design for M.Curie scientist. Color is inspired by chemical tools, tones such mainly blue and blue green color, and its contrast colors, which are pinky red and brilliant red. This project gave a new life for this urban area, which was without any colors throughout the whole area. [Bahraini has mentioned in his book about the use of colors in the city: "how to use of color is under influence of two environmental major, factor such as beliefs and protocol of the place"]. Harmonious variety of color compositions create visible comfort, at the same time psychological wellness, and powerful relation with place. This project aims to make color palettes apply to complete missing colors of this urban space.

Fig.8_Left_ Corner wall of via D.Guicciardi and via A.Bonomi
Fig.9_Right_left side of via D.Guicciardi
Foto Courtesy by Magma project, ph E.Zamponi.

Color design for public space

03. Picina Procida Milano Sport Milan municipality 8

Last project is regeneration of the Municipio 8 area of Milan, including color and design interventions on the entrance wall of the Procida swimming pool. Magma Project designed the wall, interpreting the theme of "water and waves." Magma Project, in collaboration with WAU! Milano, implemented the project with team building and the support of an Italian construction company.

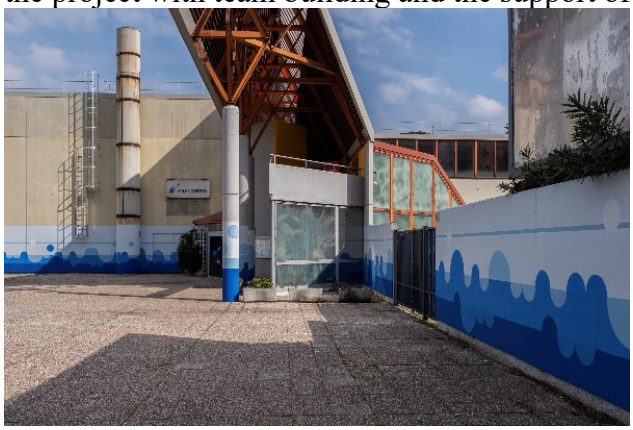

Fig.10_Entrance of Procida Swimming pool.
Previously it was cracked and anonymous urban area, after color design intervention it became pleasant public space not only for swimming pool users, but also for local residence.
Foto Courtesy by Magma project, ph D.Portanome.

The concept's theme is water, the sea, and waves. The project was created at the entrance to the Procida swimming pool of Milano Sport. Reproducing and interpreting the horizontal and vertical rhythm of the waves and transforming it into the geometric and colorful shapes of the mural's graphic

Fig.11,12_Entrance of Procida Swimming pool. Foto Courtesy by Magma project, ph D.Portanome.

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design amplifies the message, engaging everyone who passes through the space in front of the pool and welcoming them at the entrance. The idea for the collaboration between WAU! Milano and Magma project stemmed from the desire to appropriate a degraded area of the city to launch an active civic participation project that went beyond simply cleaning the spaces and restoring the walls.
Transforming the area in front of the pool, making it more usable and identifying it through the freshness and immediacy of color. Five shades of blue along with three-dimensional circular shapes are the building blocks of the graphic and color project. The background is created with horizontal lines that fade from light blue to dark blue, modulated by circles of various sizes that create a wave-like rhythm by positioning and overlapping above and below the colorful lines of the background. A team of 60 collaborators from a renowned Italian construction company painted a 250-square-meter surface.

Conclusions

Urban areas have important role in urban life more and more. The possibility to create specific identity for each urban space could improve local residences and user's life significantly. Color is important asset for creation of identity and character of urban space.
Each urban space has its own specific site character and huge potential to become an important space for aggregation and constructive communication. Color design in urban context, derived from research of history, culture, nature could be the base of its starting point as much as importance of aesthetic and artistic aspect. Because urban space is for all, and important intersection of proper lift of each city, creating strong connection with its place. The special urban place can be made by these color design projects respecting each space's own origin and can be enriched by stories of citizens and users.

Fig.13,14_Entrance of Procida Swimming pool. Foto Courtesy by Magma project, ph D.Portanome.

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Color and Culture

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Seeking Reciprocity through Light and Colour: Contemporary Art at Pitzhanger Manor

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Abstract

In recent years, contemporary art exhibitions installed in historic houses have become increasingly prevalent. A key motive is to develop an extended and more varied audience as part of a wider public programme. Sir John Soane's house, Pitzhanger Manor in Ealing, west London (1804-10), offers a series of extraordinary, characterful rooms. The context of Soane's architecture, and particularly his play of colour, light and constructed narrative, has prompted a series of contemporary artists to respond in ways that seek a reciprocity between the art and architecture.

Through a discussion of installations of paintings by the artist Antoni Malinowski and others, curated to make connections specifically relating to the use of light and colour in the house, the paper draws attention to the way in which artwork temporarily housed in historic settings may offer a re-reading of space. The paper concludes that the role of colour and light adds a further dimension to the discourse on curatorial practices for contemporary art in heritage spaces.

Keywords: colour, color, art, architecture, painting pigments, curatorial practices.

Introduction

In recent years, contemporary art installations installed in historic houses have become increasingly prevalent. A key motive is to develop extended and more varied audiences as part of a wider public programme. Artwork may respond to the tangible heritage– physical historic objects, building fabric and materiality– or to the intangible heritage, drawing out narratives of local and global social histories. Such juxtapositions may extend to create 'new modes of visitor engagement with heritage sites, including sensory, emotional, imaginative, and critical engagement.' Although this is a growing trend, 'a more critical understanding of this field is required'. (Farley and Pollock, 2022, pp. 242, 256).

Unusually among historic houses, Sir John Soane's own house, Pitzhanger Manor in Ealing, west London (1804-10) (Fig.1), offers both a conditioned white gallery space– making use of a 1939 extension– and a series of extraordinary, characterful rooms in the house itself. As a result, as noted by Richard Parry, the Head of Public Programmes at Pitzhanger Manor, the art programme has included international artists such as Anish Kapoor, Rana Begum and Grayson Perry combined with smaller, diverse shows interspersed through the house. The context of Soane's architecture, and particularly his play of colour, light and constructed narrative, has prompted a series of artists to respond in ways that seek a reciprocity between the art and architecture.

The author's book publication *Colour Beyond the Surface: Art in Architecture*, (McLachlan 2022) explores the role of artwork embedded within architecture. It considers the way in which colour, material surface, and the pictorial space within a painting may contribute to the experience of an architectural setting. The aim of this paper is to focus on the curation of temporary art installations placed in specific historic settings that may trigger alternative sensorial readings of the spatial setting.

Miwon Kwon, a Korean curator, suggests that such site-specific placing of unfixed artwork is understood as ephemeral, as 'unrepeatable and fleeting', (Kwon, 1997). While, as noted by Hedvig Mårdh,

> 'The historic house museum has become interesting as a creative space precisely because it is not a white cube or a museum built for art exhibitions, but is rather the home of people from the past. These characteristics open up numerous strategies for artists, scenographers, and curators.' (Mårdh, 2015, p.27)

Through a discussion of recent installations of paintings that were curated to make connections specifically relating to the use of light and colour in Soane's house, the objective of the paper is to draw attention to the way in which the artwork offers a dynamic re-reading of space. Drawing on this specific example, the paper aims to add a further dimension to the discourse on curatorial practices in heritage spaces.

Fig. 1 – Sir John Soane, Pitzhanger Manor, London, front façade. Photo: Author
Fig. 2 – Central vestibule, renovated to original colour and decorative marbled paintwork. Photo: Author

The setting

Sir John Soane's fascination with light and with shifting atmospheric effects is one of the most significant factors in the enduring appeal of his architecture. His use of colour, of specific pigments such as Herculean red, seen on his Grand Tour in south Italy in 1778, a deep green, and a strong yellow– applied both as pigment but also generated as light through coloured glass– are carefully choreographed to allow multiple readings of each room. Sadly, despite employing his full artistry and imagination to create a showpiece for his architectural skill, Soane's family lived in the house for only 6 years, leaving for central London together with all of their eclectic collection of belongings and paintings in 1810. A full restoration of the house was completed in 2019, including the re-creation of Soane's colourful and flamboyant decoration (Fig.2). The selection of material possessions returned to the house are inevitably edited and accrue a different, performative meaning for visitors. Artists making or exhibiting art in such site-specific contexts may draw on these traces of everyday life to invoke a social, political or spatial critique relevant to the setting. In the case of Pitzhanger Manor, however, it seems that the intangible qualities – optical plays with intense light and shadow–

as well as interconnected spatial sequences and constructed views, stimulate artists to explore an experiential reciprocity with the architecture of the house itself. A recent installation of paintings by Antoni Malinowski offers an intriguing re-reading of the complex spatial qualities of the rooms and of the paintings themselves seen in this highly charged setting.
In a brightly daylit conservatory space that runs across the garden elevation, a large canvas was placed at the north end of the room. A distorted rectangle suggested a pool of light from the window, floating on the surface of the canvas. Blue intersecting lines may be interpreted almost immediately as a representation of the window astragals, the warm ochre palette sitting comfortably adjacent to the brick wall. Looking more closely, multiple overpainted and translucent layers form a ghostly, indistinct composition (Figs. 3 & 4).

Figs. 3 & 4 – Antoni Malinowski *Shimmering Oracle*, 2022, synthetic tempera on linen, installed in the conservatory. Photos: Courtesy of the artist, ©Francesco Montaguti

In Soane's west-facing upstairs bedroom, a painting placed on an easel allows the viewer to see simultaneously the painting in the foreground and out through the window to the landscaped garden beyond (Fig.5). The abstract forms in the painting– with slanted verticals to the left and horizontal brush strokes to the right– echo the spatial relationship of close and distant views. A red canted form and thin yellow lines appear to advance, to read as akin to a frame, while the ambiguity of the softer blues and browns give depth in the pictorial space of the painting. In a further close reading, a darker oval form that anchors the eye within the formless space of the painting is suggestive of the small knob on the adjacent window shutter. Some visual connections can be attributed to the careful curation and selection of the work with an intimate understanding of the way the daylight works in the house, but others were unplanned, to be read and interpreted by the viewer. At first sight it is the colour that makes direct visual connections to the rooms in which the paintings have been installed.

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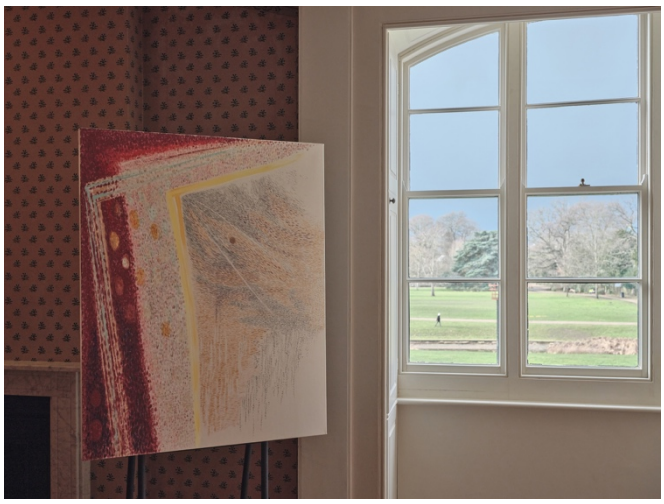

Fig. 5 – Antoni Malinowski painting *Refracted, 2024,* synthetic tempera on polyester, installed in the bedroom looking west. Photo: Courtesy of the artist, ©Francesco Montaguti

In the Eating Room, a large pink and blue painting over the fireplace chimes with the colours in the carpet and the settees (Fig. 6). Further resonances emerge between the pictorial space of the painting and the actual experience of the room, such as the way the light reacts with the pigments from different points of view, creating depth and between small architectural details and shapes in the painting. Malinowski's countless small brushstrokes create draping forms when viewed at a distance, while close up, the direction of the strokes produces a dynamic effect, particularly as the viewer moves around the space, and in changing light conditions (Fig. 7).

Fig. 6 – Antoni Malinowski painting, *Demeter*, 2020, tempera on linen installed in the Eating Room. Photo: Courtesy of the artist, ©Francesco Montaguti
Fig. 7 – Detail of painting installed in the Eating Room. Photo: Author

Malinowski has previously made paintings embedded directly onto walls and ceilings, often in collaboration with architects. For example his work with Haworth Tompkins at the Royal Court Theatre and Bush Theatre in London, the Everyman Theatre in Liverpool, and at Coin Street Neighbourhood centre, evidence a longstanding collaborative practice, (McLachlan, 2022). Each of

these embedded artworks was developed in response to the architectural space in which it is sited. The conversation between art and architecture is a carefully constructed dialogue, a scripted reading of the observed space, light conditions, patterns of use and occupation. Unlike a show in a conventional white gallery space, in Malinowski's permanent wall and ceiling paintings, there is always a sense that the painting works in consort with the architecture, seeking a resonance with the context.

At Pitzhanger Manor by contrast, the exhibition was a temporary installation of paintings, some hung, some set on custom-made easels placed in specific positions throughout the house. What is uncanny here is that the paintings were not made in response to the space, as is generally the case with his architectural interventions. The lead-in time to the show - that also included photographs by Helen Binet alluding to Sir John Soane's Grand Tour of Italy - did not allow for new work to be made by either artist. Instead a selection of paintings was made by Malinowski, together with the curator Richard Parry, from the artist's collection, considering scale and the restricted mounting conditions due to the Grade 1 Listed building. Some connections, such as the colour palettes of the pieces, were consciously made, and the placing of each work was very deliberate in making suggested parallels with particular characteristics of each room. Other less predicted associations seem to occur in the mind of the viewer seeing a painting in its immediate context in the house.

Activating light

The title of the exhibition, *Pigments and Photons*, alludes to Malinowski's signature method of engaging and activating light within the surface of the paintings through densely arrayed marks of pigments, chosen not only for the colour they reflect, but the way the light is modified by the microscopic surface. Moreover, the pigments are laid in layers, causing further reactions and interactions in the way the light is absorbed, reflected and refracted, creating an oscillating effect. His large wall painting *Spectral Flip* (2015) at the Mathematical Institute in Oxford (designed by architect Rafael Viñoly), was painted insitu over a period of months making the marks in response to the passage of the light, (McLachlan, 2022, pp.106-7). Interference pigments used as an underlay bend the light waves that fall on the surface, and react very differently to traditional subtractive earth colours such as ochre and caput mortuum. In the bedroom at Pitzhanger Manor, Malinowski's painting *Refracted* (Fig.5) is placed at an angle, slightly impeding the passage of the visitor to the house and forcing an acute view. The smooth polyester surface was first painted with acrylic mica paint with synthetic tempera on top of the reflective background. As some pigments used are matt and some are interference pigments, the colour appears entirely different when seen at an angle and the layers also seem to shift in the spatial hierarchy of the surface. The painting, *Shimmering Oracle,* (Figs. 3 & 4) uses synthetic tempera on linen*,* with yellow and golden ochre, caput mortuum, lapis lazuli and a yellow interference pigment that reflects the yellow light wavelength, while *Demeter,* layers brushstrokes of lapis lazuli, mica, smalt, caput mortuum, caput mortuum light (also called Cotê d'Azur violet), and an interference pigment that reflects blue wavelengths (Figs. 6 & 7). As the curator of an early exhibition of paintings at the Gimpel Fils Gallery in London observed 'in Malinowski's paintings, and in life, colour does not exist so much as happen' (Hills and Malinowski, 2004). The interaction of light and surface– producing lustre, iridescence, translucency and fluorescence, layered with solid light-absorbing colour– is not readily understood through conventional colour theory in art. The spatial effects are as restless, dynamic and complex as was Soane's own vision for the house.

Fig. 8 – Sinta Tantra paintings installed in the Drawing Room, Photo: Author

Two earlier art installations at Pitzhanger Manor also drew attention to Soane's optical illusions using coloured glass and mirrors to scatter light and create a distorted spatial depth.

As part of her exhibition *The Lightclub of Batavia* in 2024, artist Sinta Tantra placed two paintings with gold leaf overlaid on a deep, flat, Prussian blue, in the red-painted drawing room either side of the fireplace (Fig. 8). This south wall, sitting perpendicular to the large conservatory windows is flooded with light falling across the picture plane. The gold leaf shimmers in the light, appearing to float. The visual and spatial effect is enhanced by the multiple reflections of the work in mirrors placed opposite each other by Soane. The title of the exhibition was taken from a short story by Paul Scheerbart (Scheerbart, 1912) and makes subtle reference to Soane's use of yellow glass in the central atrium at Pitzhanger, which floods the entrance and stairwell with an ethereal glow similar to the fictive bathers who are immersed in coloured light from stained glass, rather than water, in the story. In the *Pigments and Photons* installation, Malinowski's paintings selected for the same position contain fragments of venetian Murano glass on the surface, also drawing attention to coloured light filtered through stained glass in the adjacent rooms. A later exhibition by Sinta Tantra, *Light is therefore colour*, (Tantra, 2025) sited within the artist J.M.W Turner's house in Twickenham, London, continued the theme of sensory resonance between art and architecture while making a narrative link back to Soane, as Turner was known to be a close friend and a frequent visitor to Pitzhanger Manor.

Finally, in Catrin Huber's, *Grammar of Clouds* (2012) at Pitzhanger, a projected installation on the ceiling of the Drawing Room, made a connection between her interest in fictional space and Soane's use of a painted central oculus in the adjacent Breakfast Room, which suggests a space beyond the surface and heightens the experience of the small room. In Malinowski's deep blue Lapis Lazuli painting (Fig. 8), placed directly in the Breakfast Room, a slanted oval form is easily read as resonating with the disc overhead. Both artworks encourage the eye to drift upwards. A wall mirror, placed by Soane strategically opposite the entrance from the hall, distorts the width of the room and

introduces further spatial ambiguity. Malinowski's shimmering blue painting is then reflected in the mirror seen from the vestibule and contrasts with the ochre walls.

Fig. 9 – Detail of Antoni Malinowski *Almost Seen- Lapis Lazuli* (2016), synthetic tempera on cotton duck canvas, installed in the Breakfast Room, Photo: Author

Conclusions

Alongside staged scenes that are commonplace in historic house museums, contemporary art can serve a different function– to question, challenge or interpret hidden issues in history, or invite the viewer momentarily to see their surroundings through a different lens that may resonate with narratives, politics, ethics, local and global social histories. In addition to tangible, material responses or intangible social considerations, the paper suggests that a reciprocal relationship between colour and light within the artwork and the setting adds a further spatial and experiential dimension to the discourse on curatorial practices in heritage spaces.

Sir John Soane understood the potential of fusing art, architecture and sculpture, often as agents in an artfully constructed narrative. His fascination with light and with shifting atmospheric effects is one of the most significant factors in the enduring appeal of his architecture. His use of colour, using specific pigments, but also generated as light through coloured glass, is carefully choreographed to allow multiple readings of each room. Antoni Malinowski's paintings demonstrate an acute understanding of colour and the interaction of light with material surface which resonate with the similar dynamic and ethereal effects in Soane's architectural composition to invite a deeper contemplation of colour and light in the house.

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Painted photography by Pierre Gusman.

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Abstract
In 1896, Pierre Gusman harshly criticised Nicolini's Italian chromolithographs, saying they were 'well suited to distorting judgement and distracting students at the Beaux-Arts from art that has real value'. In 1898, during his stay in Pompeii, he took numerous photographs in what can be described as an exhaustive documentary effort. His albums, preserved at the INHA in Paris, show how the artist worked, notably by applying watercolour to overexposed photographic prints, a mixed but non-reproducible process. Since the invention of photography, this practice has been overlooked in many official histories of photography, hindering the thought processes at work. The authenticity of the autoscopic gaze is thus preserved, but what about the colours? Does it manage to render the colours exactly, or are they merely evocations? Does this mean that painted photography was only an imperfect matrix?

Keywords: painted photography, Pompeii, Pierre Gusman.

Introduction


Fig. 1 – Pierre Gusman


Fig. 2 Pompeii, 1896.

Since the first trips by 'antiquarians' to Greece during the Renaissance, such as the journey of Cyriacus of Ancona[1] (Fig. 3), it has become important to bring back images to accompany archaeological observations. These drawings were disseminated through printing and engraving[2] (Fig. 4 & 5). Observations of colours, like their representations, do not seem to be an object.
Then the discoveries of Herculaneum and Pompeii erupted onto the archaeological scene shortly before the invention of photography, a fireworks display of colours and life, but one that figurative editions sometimes struggle to convey, either because of a desire to emphasise the line[3] (Fig. 6) or because of difficulties in achieving accuracy. Since its announcement by François Arago[4], colour photography has been awaited more to reproduce the colours of ancient Egypt[5] (Fig. 7) than those of ancient Greece[6] (Fig. 8), whose polychromy is difficult to capture. It was at the very beginning of the 20th century that the Lumière brothers' autochrome plate established itself as a reliable medium,

[1] Colin, J. (1981).
[2] Caylus, A. de (1764) : "Pl. XXXVII : six figures de terre cuite, trouvées à Camarina, Sicile".
Accademia Ercolanese, (1762): "Pl. 1, p.10 Apollon à la lyre".
[3] Mazois, F. (1824) : "Frontispice".
[4] Arago, F. (1839a). Arago, F. (1839b).
[5] Perrot, G., Chipiez, C. (1882) : "Tombeau de Phtah-Hotep". Bourgeois del.; J.Sulpis sc.; impr. Chardon.
[6] Aligny T., 1845 : "L'Acropole d'Athènes".

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thanks to a highly orchestrated advertising campaign that concealed its mediocre success rate (60°/°) and the fact that it required considerable skill to use. In reality, this unique product was a disappointment. At the same time, photomechanical processes competed to introduce colour into published plates. It is in this context, summarised here in broad terms, that Pierre Gusman (Fig. 1) comes into the picture. We will attempt to understand his photographic practices through the items entrusted to the INHA. This son of an engraver and engraver himself is 'an artist' who, according to the great archaeologist Maxime Collignon[1], author of *La Polychromie dans la sculpture grecque antique* (Polychromy in Ancient Greek Sculpture), went to Pompeii and 'returned an archaeologist'. (1898). First, will Pierre Gusman's few publications on the theme of Pompeii enable us to understand his approach and its evolution? Then, by setting out some historical milestones in painted photography, we will see how the photographer Pierre Gusman was able to proceed, both in the shooting and in the laboratory.

Fig. 3 –

Fig. 4–

Fig. 5 –

Fig. 6 –

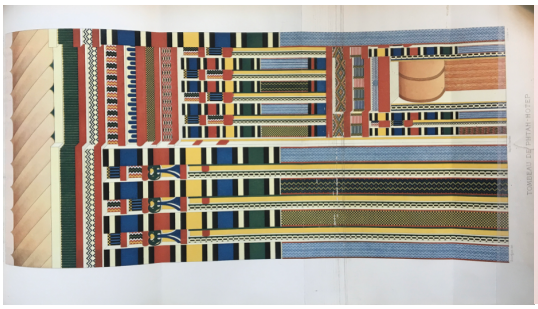

Fig. 7 –

Fig. 8 –

Pierre Gusman's editions

It was in 1899 that Pierre Gusman published the first edition[2] of Pompeii, *Pompéi, La ville, les mœurs, les arts*. (The City, Customs, and Arts), after numerous trips that allowed him to accumulate visual documents, photographs, drawings, and watercolours. As early as 1896, he had already published an article in the *Gazette des Beaux-Arts*[3] entitled 'Quelques peintures de Pompéi' (Some Paintings from Pompeii), in which he analysed, as a practitioner, the ancient painting techniques that archaeologists were still debating at the time. The article is illustrated with plates, which can be found in the Gusman archives of the INHA and which Andrea Milanese[4] catalogued in 2009-2010 and Delphine Acolat[5] consulted in 2017 for her work.

In the richly illustrated 1899 book, only 12 plates are in colour, out of more than 600 drawings in the text and 32 watercolours. These are (Fig. 9 - 20) : I : Vénus, Léda, Bacchante ; II : Porte stabienne, rue de Stabies ; III : Peinture de la Thermopole de la *strada di Mercurio*, Fontaine de Jouvence, Paysage exotique ; IV : *Casa della Caccia*, Maison « *del Poeta Tragico* » ; V : Combat naval, La

[1] Collignon, M. (1898).
[2] Gusman, 1899.
[3] Gusman, P. (1896).
[4] Inventaire in INHA.
[5] Acolat, D., Maligorne Y. (2023).

vendange, Le vin ; VI : portraits pompéiens : 1région VII, insula XII, n°26 ; 2 région VIII insula V, n°39 ; 3 région VII, insula IV, n°31 (*Casa di Arriana*) ; VII portraits pompéiens : 1région IX, insula I, n°7 ; 2 région VII insula I, n°47 ; 3 région VI, insula VII, n°21 ; 4 région IX, insula V, n°4 (Maison de *Holconius*); 6 région IX insula V, n°11 ; VIII Portraits pompéiens : 1région VI, insula VII, n°23 (Casa di Apollo) ; 2 région I insula III, n°30 ; 3 région I, insula II, n°6, Le supplice de Dircé (peinture de la maison des *Vettii*) ; IX Premier style décoratif (*Casa del Centauro)*, Second style décoratif (*Casa delle Nozze d'Argento*) ; X Troisième style décoratif variété égyptienne, (Maison de *Jucundus*) ; XI Quatrième style décoratif, (Maison des *Vettii)* ; XII Mosaïque scène comique (Villa de Cicéron), Fontaine en mosaïque (*Casa dell'Orso*).

Fig. 9 - 15–

Fig. 16 –20-

The technique is traditional : it undoubtedly seeks accuracy, as all artists before Pierre Gusman sought it. An example of this is this plate from the work consulted by Pierre Gusman: Raoul-Rochette[1] although he paid the painters and engravers of the first editions out of his own pocket, does not seem to have noticed the inaccuracies in colours and lines in this later publication! As an artist, Pierre Gusman seems to want to render its accuracy: could it be rather an impression, certainly accurate for the painter, of the effects of colours? To our contemporary eye, do we not see echoes of an artistic era in which Impressionism permeated aesthetics? Could this mean that Pierre Gusman was content with the lack of photographic accuracy? We will return to this point later.

Then in 1924, after the autochrome plate and its disappointments, Pierre Gusman returned to his favourite subject: Pompeii, in a work entitled[2] *La décoration murale à Pompéi* (Wall decoration in Pompeii), almost three decades after the article mentioned above. The presentation recalls the German and Italian chromolithographs of the past, which 'sufficient reproductions for the archaeologist (sic), are not particularly appealing to the artist and craftsman'. As examples, let us compare these publications by 'Flore' from the same half-century: Manon Dardenne[3], in her articles from 2024, to which I refer for the archaeological study of watercolour and photographic subjects, also highlights the significance of all these watercolours sold by the artist to the Beaux-Arts, insofar

[1] Cf: "Carnet noir de Pierre Gusman", Archives de l'Institut de France, fonds Gusman. And Raoul-Rochette, D.(1833) ; Raoul Rochette, D. (1836) ; Raoul-Rochette, D., Roux, N.H., (1867).
[2] Gusman, P. (1924).
[3] Dardenne, M. (20 décembre 2024).

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as she sees them as a conservation effort on the part of Pierre Gusman, who was aware of the dangers to which the Pompeian works themselves were exposed when left to the elements.

Pierre Gusman's approach is that of an 'artist' keen to pass on ancient models. But having 'become an archaeologist', he knows how to use photography as a pragmatic tool. It is this pragmatism that we often find in the photographic practice of archaeologists. Before attempting to understand how Pierre Gusman colours his photographs and for what purposes, I will revisit a few photographs painted before his. It is worth noting that for a long time this topic was completely ignored, no doubt due to the controversy surrounding the birth of photography, between art and science, a very French controversy, to be sure!

Any photographs painted before 1896

As demonstrated by the papers presented at the 2024 Amsterdam symposium, including that of Paula Ogayar Oroz[1], daguerreotypes could be painted with a brush. This practice, which was very common in the United States of America[2], was mainly used in portraiture. However, a daguerreotype[3] of a painting by Ingres, 'Stratonice' (Fig. 21), dated around 1840, attests to this practice in Rome. We do not know who painted it, but it must have been someone close to the Villa Medici when the painter was in charge. Was it the painter who experimented with colours? The dress is pink in the painting kept at Chantilly and blue in the later painting in Montpellier, which is reversed, as is the daguerreotype. Let us remember that this is a painted daguerreotype produced in an artistic context, without public reception, or at least not until much later.

In the archives of Jacques-Ignace Hittorff[4], champion of ancient polychromy, two colour photographs signed 'Intergugliemi, Palermo' (Fig. 22), coloured, are preserved, without dating - it is possible to envisage their acquisition by the son of Jacques-Ignace Hittorff. Dedicated to contemporary rather than archaeological subjects, these are popular photographs. Neither archaeological nor artistic, they are evidence of semi-industrial production aimed at Grand Tour travellers. Hand-colouring technique, using a doll? These are exceptions in the architect's documentation. - Other examples of the water carrier with different colours can be found online.

Finally, another painted photograph catches our attention: that of Gustave Le Gray[5], which recently appeared at auction: (Fig. 23) 'Palmyra'. There is a three-year gap between the date the photograph was taken (1860) and the date the colours were added (1863). This photograph remained in his home and was for personal use, and there is no documentation to tell us whether Eugène Le Gray regularly practised painted photography in Egypt, where he spent the second half of his life. It was not until the 21st century that this practice came to be appreciated: the purchase price remained relatively modest for this artist, a sign that painted photography is still difficult to accept.

[1] Paula Ogayar Oroz : "Training the eye, an exploration of hand-coloured daguerreotypes and their examination", in "*Colour Photography and Film: analysis, preservation, and conservation of analogue and digital materials*" Amsterdam, The Netherlands, Thursday 12 and Friday 13 September, 2024.

[2] Brunet,B., Becker, W.B. (2013).

[3] Pascale Picard-Cajan et alii, (2006) : fig. 260, p. 353.

[4] Kiene,M. (2024); Kiene, M., Lazzarini, L., Marconi,C. (2016).

[5] Auction Bea 2011, 81 000€. Sold, ['Panorama de Baalbeck, Temple de Bacchus et les six colonnes, peinture à l'huile sur tirages photographiques d'après négatifs papier montés sur carton, signée et datée : Gustave Le Gray 1863, 266 x 568 mm. Prise de vue en novembre 1860. Il est possible qu'il s'agisse de la vue de « Bulbecq » (sic) mentionnée dans l'inventaire après décès de l'artiste (5 août 1884), accrochée au mur dans la pièce à droite de l'entrée de sa maison au Caire Bibliographie : Sylvie Aubenas, Gustave Le Gray 1820-1884, Bibliothèque Nationale de France/Gallimard, 2002, reproduit p. 285'].

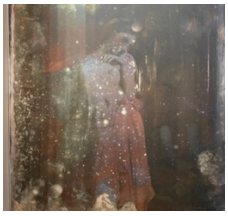
Fig. 21 -


Fig. 22 -


Fig. 23 -

And let us assume that Pierre Gusman was not familiar with these photographs. Was he an engraver who became a photographer?

Pierre Gusman's photographic archives

Pierre Gusman's photographic cartoons, preserved at the INHA, bear witness to his intensive practice of taking photographs on location during his stays in Italy, thanks to the possibility of instant photography. (Fig. 2[1]).

The layout of the cards shows photographs of Pompeii from 1896, 1898, 1902 and 1904, but not all of them are dated. A few annotations indicate the location. These small-format prints number between two and ten, or even more, per cardboard page, with a number referring to the negative. Pierre Gusman also supplemented his documentation with photographs purchased from museums or commercial sources: Alinari; Brogi; Ediz. Esposito; A. Giraudon; Robert Rive; Romano; Sommer; and anonymous photographers. Finally, photographs of drawings and watercolours by Pierre Gusman himself are also present, in addition to engravings and extracts from works relating to his subjects of study.

By examining the INHA files, let us try to understand his approach to these photographs, which were never published as such during his lifetime : preparatory work: shooting, photographic laboratory work, editing, preparation for publication, publication.

Firstly, he did not allow himself to be constrained by technical issues: needing a panoramic view to capture a building, he took three shots which he then stuck side by side.: (Fig. 24). The finesse of the joints demonstrates both his archaeological approach and his photographic technical mastery.


Fig. 24-


Fig. 25 -


Fig. 26 -

In 1904, before the hoped-for autochrome plate, in the publication of his work devoted to the Villa Tibur, for plate X (Fig. 25) based on an Alinari photograph, 'Red marble satyr found at Villa Hadriana', he used monochrome paper to reflect the colour of the material used in antiquity, in this case red marble; a process commonly used by Braun at the time. This substitution method produces

[1] " POMPÉI", 1896, Fonds Gusman, INHA.

a monochrome, which I would be tempted to describe as achrome[1]. In addition, Pierre Gusman plays with different photographic emulsions in his prints to capture tones and brightness[2] (Fig. 26).
Both in terms of line and colour, Pierre Gusman uses tricks and DIY to compensate for technical shortcomings.
In the absence of colour photography, watercolour was the technique preferred by archaeologists, particularly when presenting their findings to the bodies financing their projects: Maxime Collignon emphasised how only watercolour could capture the brilliance of these colours[3]. But this was an *unicum.* Did Pierre Gusman attempt to reproduce the colours of the watercolour?

Did we move from annotation to process?
In the Gusman collection, we can see several uses of photographic prints in the publishing process. Were there several stages involved?
Some prints are annotated, as in the previous slide, but also with handwritten notes, with the words themselves written on the photographic emulsion (Fig. 27). The colours of antiquity are written (« rouge, jaune, brun » red, yellow, brown). Colour annotation is already a practice used by archaeologists, as seen in this 1824 drawing by Jacques-Ignace Hittorff[4] in Sicily. (Fig.28) However, this memorisation process differs in different professions due to the techniques used: the artist in front of the colours of his landscape for future colouring or watercolour painting. The photographer in his laboratory for the engraver or printer. In the first case, these annotations memorise, but in the second, they organise. We note the terms used by Hittorff to describe the nuances. (« *fond bleuâtre, mais les détails distincts. (...) mais coloriées quoique vaporeuses (...) jaune vif. (...) d'un verd de vessie foncé, (...) verd de gris. (...) sable, très jaune (...) en clair.* » ('bluish background, but distinct details. (...) but coloured, albeit hazy (...) bright yellow. (...) dark bladder green, (...) greyish green. (...) sand, very yellow (...) light.')


Fig. 27-


Fig. 28 -

The attestations of overexposed photographs result from the addition of colours so that the photogenic design can guide the artist's hand in the authenticity of the autoscopic gaze. He then adds colours using watercolours. Applied directly onto the emulsion (Fig. 29-35), they show quick brushstrokes, like markers, or transparent colours, revealing the emulsion like coloured drips.….

[1] Frizot, M. (2018).
[2] INHA, Fonds Gusman, Carton 1, dossier 3.
[3] Collignon, M. (1899) ; Collignon, M. (1901) ; Collignon, M. (1905).
[4] Album GG8 2160, Fonds Hittorff, Cologne, Universitäts- und Stadtbibliothek Köln.

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Fig. 29 - Fig. 30 - Fig. 31 - Fig. 32 -

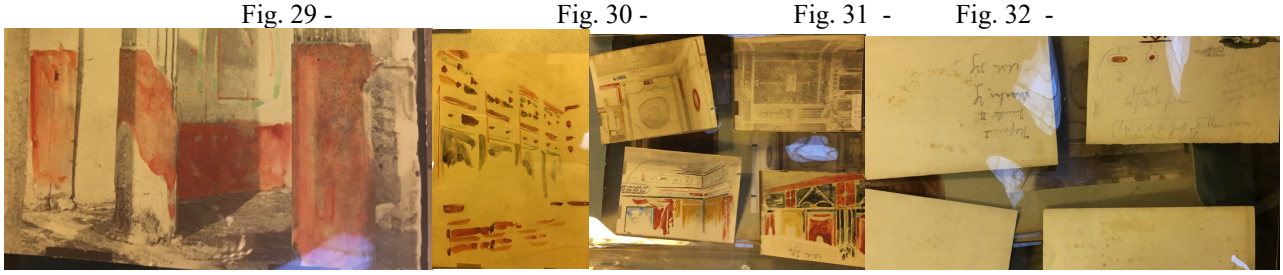

Fig. 33 - Fig. 34 - Fig. 35 –

or even bars superimposed, in the almost total disappearance of the photographic background in extreme overexposure. Not only on the emulsion, but also on the back of the print are colour annotations. These are working documents.

Conclusions

Since Pierre Gusman was keen to preserve these stages but did not use them directly, we can hypothesise that the engraver, convinced as he was - he began his career in this art, edited the magazine *Byblis* for twenty years, and his testamentary work[1] *Elské* (1936) makes no use of photographs, either directly or indirectly - his photographic practice was based on the photomechanical processes used by publishers at the time. Since colour photography cannot render ancient colours any better than chromolithography, he sought out processes that he considered so inadequate that in his works devoted to decorative art[2], he refrained from dealing with ancient painting: « *De même, dans le grand ouvrage de Nicolini, les nombreuses planches en couleurs ne traduisent aucunement le sentiment et l'harmonie des peintures antiques; aussi est-il regrettable que de pareils documents soient consultés par les élèves de l'École des Beaux-Arts, qui doivent trouver peu d'attrait à l'étude de ces chromolithographies italiennes, bien faites pour fausser le jugement et détourner d'un art qui a sa valeur*. (p.200-201) » : Similarly, in Nicolini's great work, the numerous colour plates in no way convey the feeling and harmony of the ancient paintings; it is therefore regrettable that such documents are consulted by students at the École des Beaux-Arts, who are unlikely to find much appeal in studying these Italian chromolithographs, which are well suited to distorting judgement and diverting attention from an art form that has its own value.

His final work on Pompeii in 1924[3] was therefore an attempt to introduce colour through modernity: according to recent studies reported by Manon Dardenne, these colours were applied using stencils. I quote: « Sur une impression très claire, vraisemblablement lithographique, les couleurs (gouache et aquarelle) ont été appliquées au moyen de brosses dans les parties découpées de pochoirs, des feuilles de zinc ou de cuivre, dont le contour de la découpure épouse celle du dessin[4] » : On a very clear print, probably lithographic, the colours (gouache and watercolour) were applied with brushes through the

[1] Gusman, P. (1936).
[2] Gusman, P., (1909) ; Gusman, P., (1913) ; Gusman, P., (1914).
[3] Gusman, P., (1924).
[4] Dardenne,M. (2024).

cut-out sections of stencils, zinc or copper sheets, whose cut-out contours match those of the drawing. Is this the Finley principle?
In conclusion, Pierre Gusman used photography as his *technè*. As an artist-archaeologist, he freely sought his own personal path. Could we say that he painted photographs, that he added colour to monochrome prints without seeking painted photography, since he was looking for a reproducible medium?

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A Contextual Analysis of Colour in Andy Warhol's Screen Prints in Relation to Commercial Colour Trends of the 1960s, 1970s, and 1980s

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Abstract

This paper investigates the use of colour and colour combinations in Andy Warhol's iconic screen prints, analyzing them against the backdrop of popular historical colour palettes in design, fashion, and interiors. While Warhol is rightly considered a figurehead of the Pop Art movement and his early colour choices are emblematic of the 1960s, this study argues that his palette underwent a significant and gradual evolution in subsequent decades, influenced by external commercial colour trends. Trained as a commercial artist and known for his keen sensitivity to popular culture and fashion, Warhol's practice—including his frequent solicitation of aesthetic input—suggests a professional responsiveness to the prevailing zeitgeist. In this paper I hypothesize that Warhol's colour choices adapted to the commercial colour trends of the 1960s, 1970s, and 1980s.

The research material comprises 39 Warhol screen prints from the collection of the Andy Warhol Museum of Modern Art in Medzilaborce, Slovakia (Fig. 1). The colours of these works were systematically measured and recorded using the Natural Colour System (NCS). Analysis focuses on the NCS parameters of whiteness, blackness, and chromaticness, utilizing the NCS colour wheel and colour triangle (Bergström 2008). Warhol's palettes from the three decades are plotted and compared against documented commercial colour trends established through a literature review (Eiseman & Recker 2011, Valan 2012, Castelli 2021). Furthermore, the study incorporates an analysis of the artist's own statements on colour from published interviews and writings (Dufresne 1988, Goldsmith 2006, Gopnik 2020, Warhol 1975, Warhol 1983).

Keywords: Andy Warhol, Pop Art, Colour Palette, Commercial Trends, Screen Prints

Fig. 1 – Marilyn Monroe, screen print on paper (1967), "Andy Warhol. Dialogue with Pop Art" exhibition in Krakow

Introduction

Andy Warhol was one of the most famous artists of the 20th century. He created a prolific body of work, with over 9,000 paintings and sculptures and nearly 12,000 drawings documented by the Andy Warhol Foundation, though the exact number is difficult to define due to his extensive output in various media. He also produced over 19,000 prints, 60 feature films, more than 4,000 videos, and countless other works, including photographs and books (The Andy Warhol Foundation for Visual Arts)

Before Andy Warhol became one of the leading figures of Pop Art, he worked as an illustrator and graphic designer for over 10 years, developing his distinctive visual language. While still a graphic design student at the Carnegie Institute of Technology in Pittsburgh, he encountered the works of American colour psychologist and art historian Faber Birren (Eiseman, 2015). Trained as a

commercial artist, he used repetition and printing techniques characteristic of advertising. The beginnings of Warhol's artistic career coincided with the period of the so-called "battle of the brands", owned by companies competing with each other for specific market segments (Grudin, 2010), as well as the beginning of critical voices regarding forms of advertising (Packard, 1957). Warhol was fascinated by the world of commerce, famous brands, film stars and the media (Warhol 1975). His interests perfectly matched the Pop Art movement that was developing in the United States in the early 1960s, whose creators used images of popular products or comic stripes in their works and sought to achieve the impression of mechanical reproduction of the image, losing the trace of the hand (Foster 2023). Andy Warhol's choice of print medium, the stencil technique known as screen printing (or silkscreen, although other materials have long substituted for silk), for virtually all his work, placed him in an advantageous position for what he ultimately sought – fame (Castleman 1990). In the 1970s and 1980s, Warhol expanded his activities into the field that he called "business art" (Warhol 1975). His Factory became an attractive centre for the "production" of art, drawing visitors from the worlds of show business and politics. The multiple reproduction and multiplication of images resulted from Warhol's use of the silkscreen technique, which simultaneously led to the objectification and de-realisation of people and events. Warhol exposed a world dominated by market mechanisms, in which art ceased to be something unique (Folga-Januszewska 1998).

Colour in Andy Warhol's work

Although colour in Warhol's work has not been the subject of a separate academic study, references to it appear in the literature on the artist (Castleman 1990, Honnef 2002, Gopnik 2020), and the process of colour selection was also described by the artist's colleagues and collaborators from the days of his famous Factory Studio (Dufresne 1988, O'Hagan 2015)

Warhol himself rarely referred directly to the role of colour in his works, leaving the interpretation to the viewer. When discussing colour, he trivialised its role, using his characteristic ambiguity and irony. Among the artist's most famous statements on colour are:

"As for whether it's symbolic to paint Monroe in such violent colours: it's beauty, and she's beautiful, and if something's beautiful, it's pretty colours, that's all." (Warhol 1975); "You'd be surprised how many people want to hang an electric chair on their living-room wall. Especially if the background colour matches the drapes." (Warhol 1975); "I've always said that silver was my favourite colour because it reminded me of space" (Warhol 1975)

In the early days of his career, Warhol used artistic oil paints (Honnef 2002), which he later replaced with industrial acrylic paints in cans and sprays, screen printing inks and fluorescent paints. Warhol liked to use paint "straight from the can" without mixing colours (Temkin 2008). This was in line with his preference for multiplication, standardisation and machine production. In a well-known interview with Gene Swenson, Warhol said, "Everybody should be a machine" (Sichel 2028). In visual identification and advertising, highly saturated colours have greater potential to attract attention than muted colours (Carter 2001). Descriptions of the creation of Warhol's silkscreen prints mention the trade names of paints: Liquitex, Benjamin Moore, DayGlo (Dufresne 1988, Temkin 2008).

In the early 1960s, the colours used by Warhol in paintings such as Campbell's Soup (1962), Peach Halves (1962) or Coffee Label (1962), corresponded to the actual colours of the brands (Honnef 2002), which resulted in the frequent use of colours such as red, blue, yellow and green. Later, it turned out that the technique that best suited Warhol's artistic ideas was screen printing. Originally used in fabric printing, Warhol had been familiar with it since his student days (Foster et al., 2023). It involves the use of a rectangular frame with a mesh stretched over it and an image template as a matrix for applying paint to paper, canvas or other material. The number of screens prepared corresponds to the number of colours used. Historically, silk screens were used, but these have now been replaced by metal or synthetic fibre screens. Exposed screens can be used repeatedly, after being cleaned of paint, allowing colours to be changed freely (Sampson 2017). Warhol wanted other people to be able to print his works, but he always evaluated the colours used (Hahn 1972). An expression

of the style of the 1960s, a period of the Cold War and the race between the United States and the Soviet Union in space technology, also known as the "space race" (Eiseman L., Recker K 2011), was the colour silver, which became Warhol's signature colour. Silver played a significant symbolic and material role in Andy Warhol's work, appearing in his iconic Factory' Studio, which was covered in foil and paint, and his "Silver Clouds" installation. He also used silver in his art, with gelatin silver prints and paintings like "Silver Car Crash" featuring silver as a key visual element, connecting his work to themes of the future, space, Hollywood glamour, and narcissism (Goldsmith 2004). In 1972 the colour base of the canveses was painted with the broad and restive strokes of Action Painting. For the prints, screens were made to show this great variety of texture and the portrait photo-screen was accompanied by crayon squiggles. As this was essentially what Warhol had been doing with his screens , printing photographs in black over painted grounds, it was merely a variation to start making collages of coloured paper and have them photographed for screens, instead of having to cut out the shapes. Warhol used this college method for most of his print projects between 1975 and 1980 (Castelman 1990)

The foundations of Warhol's financial success were his portraits. Since 1973 he devoted a substantial part of his career to produce portraits of acquaintances (collectors, artists, dealers) , famous people, and the rich. Stylistically Warhol moved from the multi-image portrait to single images, broken up by a collage underlay or textured background to very simple single images using standard colours and compositions. In some of the painted versions of Ladies and Gentlemen series (1975), the photo-screen was placed over a wildly brushed, multicolour base. The collage in the screenprints was casually but decisively composed so that a beige, tan or brown colour appears on the area of each face (Castelman 1990).

Commercial Colour Trends of the 1960s, 1970s, and 1980s

Since Warhol drew on popular culture the goal of this paper was to examine whether the historical colour trends characteristic of subsequent decades: the 1960s, 1970s, and 1980s had any influence on his work. By 'colour trends', I mean cyclical changes in the shade, brightness and saturation of colours preferred by consumers of consumer goods in the fashion, interior design and automotive industries in the American and European markets. The analysis of historical colour palettes is carried out in accordance with accepted time periods, which may cover a varying number of years. In his Umbrella Diagram, Trino Clini Castelli divided the years 1950–2010 into ten-year cycles, which were then divided into two-year phases (Castelli 2021). Other researchers (Diane T., Cassidy T. 2005) point to seven-year cycles between successive phases, referred to as: high chroma (bright) colours to multi-coloured, to subdued, to earth tones, to achromatics, to purple phases and back to high chroma colours. This work adopts cycles corresponding to the successive decades in which Andy Warhol pursued his artistic activity: the 1960s, 1970s and 1980s. This division is analogous to those used in studies on art and design (Foster H. et al. 2023). This is a preliminary classification that requires further clarification. I referred to the analysis of color trends, developed by authors such as Leatrice Eiseman and Kaith Recker in "PANTONE. The 20th Century in Color," and Francesca Valan in „Il linguaggio cromatico" (fig. 1)

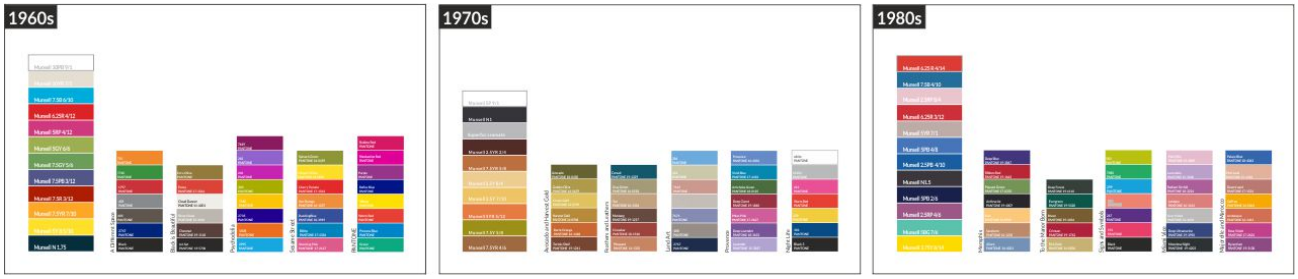

Fig. 2 – Summary of colour trends from the 1960s, 1970s and 1980s (Eiseman L., Recker K 2011, Valan F. 2012)

The 1960s were a decade of social and cultural revolution and colors reflected the spirit of change. Bold, chromatic contrasts based on primary and secondary colors. The era of plastic and forms inspired by the space race. Synthetic fabrics became more common, enabling brighter, more saturated colors in fashion and home goods. Bright, psychodelic colors, such as electric orange, hot pink and lime green became popular (Eiseman L., Recker K 2011).
The fuel crisis of the early 1970s casts doubt on the futuristic optimism of the 1960s. Environmental movements emerge, proposing a return to environmentally friendly materials and reduced consumption. The saturated colours of the 1960s are replaced by natural browns, greens, yellows and oranges. The hippie generation draws inspiration from Far Eastern cultures. The end of the 1970s is inspired by disco style – shiny surfaces and intense colours (Becker D. 2026).
The 1980s were a time of intense economic growth and the rise of the Yuppie Generation. Colour television became widespread and the era of personal computers began. In 1981, the Memphis group made its debut at the Milan trade fair. There was a return to saturated colours, with a particular emphasis on shades of blue, purple and pink. Polychromatic compositions appeared, often combined with white, black and grey (Valan F., 2012).

Measurement and analysis of Warhol's original screen prints
During the exhibition "Andy Warhol. Dialogue with Pop Art" which took place from 30 May to 29 August 2025 at the Cogiteon Małopolska Science Centre in Krakow, 58 original works by Andy Warhol from the collection of the Museum of Modern Art in Medzilaborce, Slovakia, were presented. These included paintings on canvas and paper, sketches, and commercial works from the 1950s, 1960s, 1970s, and 1980s. The colours of 39 of Warhol's works were measured and recorded in Natural Colour System notation for further analysis (Fig. 2). These were the following works: Marilyn Monroe – 6 colour versions, silkscreen on paper (1967), Jackie, silkscreen on canvas – 2 versions (1968), Mona Lisa – 2 versions, silkscreen on canvas (1963), Flowers – 8 versions, silkscreen on canvas (1968), Ladies and Gentlemen – 3 versions, silkscreen on paper (1975), Skull – 4 versions (1976), Andy Warhol Self Portrait – 4 versions, silkscreen on canvas (1986), Wayne Gretzky, silkscreen on paper (1981), Lilian Carter, silkscreen on paper (1981), Hans Christian Andersen portrait – 2 versions, silkscreen on paper (1987), Hans Christian Andersen 399 (fairytales) – 6 versions, silkscreen on paper (1987).)

1960s	1970s	1980s
Marilyn, 1967 (6 versions), Flowers, 1968 (8 versions), Jackie 1968, (2 versions)	Ladies and Gentleman, 1975 (3 versions), Skull, 1976 (4 versions)	Wayne Gretzky 1981, Lilian Carter 1981, Hans Christian Andersen (2 versions) 1987, H Ch A fairy tales, 1987 (6 versions), Self-Portrait 1987 (4 versions), Reigning Queens 1985, Mona Lisa 1983
NCS S 3002 B, NCS S 2502 B, NCS S 2030 R30B, NCS S 2002 Y50R, NCS S 1060 Y, NCS S 2020-Y90R, NCS S 5020 R20B, NCS S 7500-N, NCS S 6020 B70G, NCS S 1515 G40Y, NCS S 6020 R90B, NCS S 1500 N, NCS S 2030 R30B, NCS S 1080 Y, NCS S 3020 G, NCS S 2070 R, NCS S 9000 N, NCS S 3040 Y20R, NCS S 4040 R20B, NCS S 5020 R40B, NCS S 6010 Y70R, NCS S 5002 B, NCS S 6002 B, NCS S 7502 B, NCS S 0580 Y80R, NCS S 2070 R, NCS S 2065B, NCS S 3560 G, NCS S 2030 R30B, NCS S 0580 Y, NCS S 3050 R60B, NCS S 3560 G, NCS S 1000 N, NCS S 3560 G, NCS S 0580 Y80R, NCS S 0580 Y, NCS S 3050 R60B, NCS S 3560 G, NCS S 2030 R30B, NCS S 0580 Y, NCS S 2070 R, NCS S 3560 G, NCS S 2065 B, NCS S 3050 R60B, NCS S 3560 G, NCS S 3050 R60B, NCS S 2060 R30B, NCS S 0580 Y80R, NCS S 2030 R30B	NCS S 4020 Y40R, NCS S 2050 Y80R, NCS S 0540 R10B, NCS S 9000 N, NCS S 5040 Y70R, NCS S 1080 Y, NCS S 2050 Y90R, NCS S 3030 B, NCS S 2502 Y, NCS S 2040 Y30R, NCS S 5020 Y70R, NCS S 2050 Y40R, NCS S 2050 Y80R, NCS S 5040 R70B, NCS S 2030 R30B, NCS S 2050 R10B, NCS S 1020 B10G, NCS S 2030 Y20R, NCS S 1515 G20Y	NCS S 2070 Y10R, NCS S 2075 Y70R, NCS S 1055 B, NCS S 2020 G30Y, NCS S 3502 B, NCS S 4040 R90B, NCS S 3040 B10G, NCS S 3040 B80G, NCS S 3050 R, NCS S 5040 Y90R, NCS S 1040 R20B, NCS S 1002 R, NCS S 2070 Y90R, NCS S 1030 G20Y, NCS S 1050 B, NCS S 1050 R30B, NCS S 1070 R, NCS S 5040 R60B, NCS S 2502Y, NCS S 3560 Y90R, NCS S 8502 Y, NCS S 2030 R70B, NCS S 0570 Y90R, NCS S 3040 B20G, NCS S 2050 R30B, NCS S 3050 B, NCS S 3030 R70B, NCS S 1050 Y, NCS S 0502 Y, NCS S 8502 Y, NCS S 5040-R80B, NCS S 2040-B, NCS S 0550-G90Y, NCS S 3060-Y20R, NCS S 0300 N, NCS S 1505-R70B, NCS S 2030-R70B, NCS S 5030-R90B, NCS S 7020-R90B, NCS S 1502-B, NCS S 1020-R90B, NCS S 1050-R90B, NCS S 5040-R90B, NCS S 1080-Y80R

Fig. 3 – Colours used by Andy Warhol in his works from 1967 to 1987, measured and recorded in the NCS

The NCS Colourpin Pro was used for measurement to initially indicate the colour notation, which was then compared with the NCS Index 2050 colour chart to rule out any errors. Fluorescent colours were excluded from the measurements. A total of 137 NCS notations were recorded; 68 colours were from the 1960s, 22 from the 1970s and 47 from the 1980s.

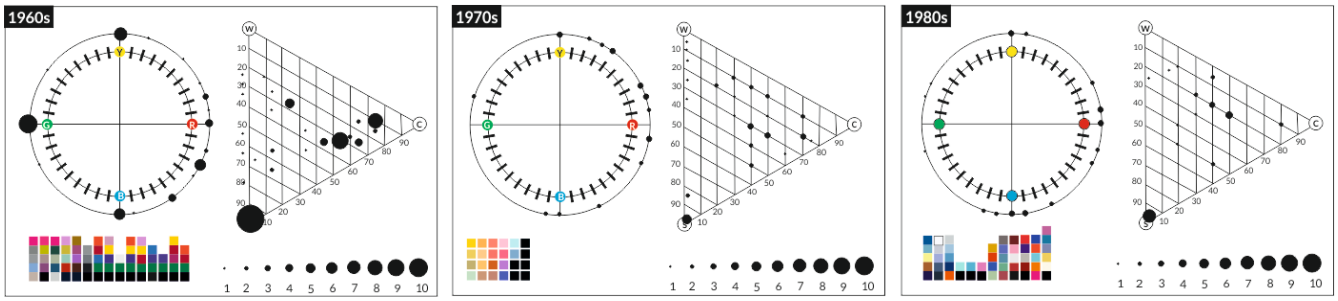

Fig. 3 – Analysis of the colours used in Andy Warhol's works presented at the exhibition 'Andy Warhol. Dialogue with Pop Art' using the NCS colour wheel and NCS colour triangle.

The obtained colour notations were compared in terms of the location of the colour in the NCS colour triangle and the NCS colour circle (Fig. 3). Colour measurements from the 1960s are dominated by colours derived from NCS Elementary Colours (Y, R, B, G) with high chromaticness. Chromatic colours are combined with black, which emphasises the photographic image of the object. In the 1970s, colours located between NCS Yellow (Y) and NCS Red (R) in the NCS Colour Circle dominate. Whiteness increases and chromaticness decreases. In the 1980s, more colours similar to NCS Blue (B) and NCS Red (R) appear, and whiteness is higher than in the 1960s and 1970s.

Conclusions

Andy Warhol created an impressive number of works in which colour significantly influences the visual form. Through colour versions of the same work, he explored the relationship between colour and form, changed the symbolism of the image (Marilyn Diptych 1962) and obtained unique works using the industrial technique of screen printing.

Andy Warhol's works were and continue to be an inspiration not only in the world of art but also in the field of commercial graphics and design. The study shows that the influence was mutual. As an artist, Warhol remained in a symbiotic relationship with the commercial world, redefining and expanding the scope of art. In creating his "business art" (Warhol 1975), he used colours in a way that was somewhat analogous to design. As the study showed, Warhol's colours underwent changes over the years, which may also have been influenced by commercial colour trends. Obviously, confirmation of this thesis requires further research due to the insufficient number of works analysed.

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Color and Education

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An illusive approach engaging colour, lighting and interior design

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Abstract

Optical illusions challenge the boundaries between physical reality and human perception. Some widely known examples of optical illusions include ambiguous images, impossible objects, colour confusion, and size uncertainty. While optical illusions usually bring in positive experiences for which viewers take pleasure in the surprises, they could also cause disturbance if were applied unintentionally. Design students who specialise in colour, lighting and interior are responsible for creating spaces that communicate and represent their identity effectively. Visual experience is important for indoor spaces since it significantly impacts our interaction with the surroundings. By studying the ways our visual system responds to the external signals and how our brain processes the visual information, students will develop a deeper understanding of the formation of visual perception and its by-product optical illusions. This project presents a case study of visual perception learning through the curiosity, understanding, and application of optical illusions in a 5-day design student workshop. The workshop consisted of demonstrating a range of optical illusions, lectures on the fundamental bases of special visual effects, exercises on analysing optical illusion examples, and reimaging an Olympic site into an effective illusion-themed hotel.

Keywords: perception, illusion, colour, lighting, interior design.

Introduction

In the context of the School of Design's workshop programme at the Politecnico di Milano, the design theme related to visual phenomenologies in interior design has been proposed to students.

The identified area is the design of the hospitality spaces. Still, the main attention required of the students, rather than the mere aesthetic aspect of the spaces, was to create an environment with distinctive morphological characteristics. The decision was made to develop the interior design for a themed hotel focused on optical illusions.

In everyday contexts, optical illusions are often associated with playfulness, surprise, and aesthetic pleasure. However, when they emerge unintentionally in designed environments, they may lead to disorientation, discomfort, or misinterpretation of space. This dual nature is particularly relevant in the fields of colour, lighting, and interior design, where professionals deliberately shape visual experiences that influence how users perceive, navigate, and emotionally respond to spaces. Designers therefore carry a significant responsibility: to understand not only the physical properties of light and colour, but also the perceptual processes through which the human visual system interprets these properties.

The Colour Workshop

The five-day workshop was designed for students in spatial design disciplines, such as architecture, interior design, and urban planning. It aimed to inform them with both theoretical knowledge and practical considerations for applying optical-illusion effects to maximise the intended purpose across different types of spaces.

The workshop encouraged students to think critically about the mechanisms of visual *trickery* and to apply these strategies creatively in the designated space. The workshop consisted of demonstrations, lectures, hands-on exercises, and group work. The structure was designed to help students observe

phenomena, understand the fundamentals, identify and appropriately explain existing examples, and apply their learning in practice.

Teachings in the Colour Workshop

Workshops and flipped classrooms have been proven to be powerful learning tools; students have the opportunity to tackle real case studies and engage in fast-paced activities that help them to grasp notions in a quick, satisfying way (Amresh, Carberry and Femiani, 2013). In our case, the final aim was for the students to produce projects of hospitality interior design with a focus on optical illusions at a concept level of definition. However, the heterogeneity of students' skills has made it essential to introduce fundamental concepts in lighting, colour, and visual perception to enable them to work effectively. Then, after presenting the workshop project and stating the deadlines for the various steps, some alignment lessons were held.

Ice breaking

The first exercise, to break the ice, was proposed to prompt the class with choices that can be made when choosing a specific shade of colour instead of another, when the choice falls on a hue, according to a concept one wants to express, etc.

They were therefore asked to produce a 5×5 grid of full colours that best described a concept they chose, and to add a comment and their thoughts on the reasons for their choices.

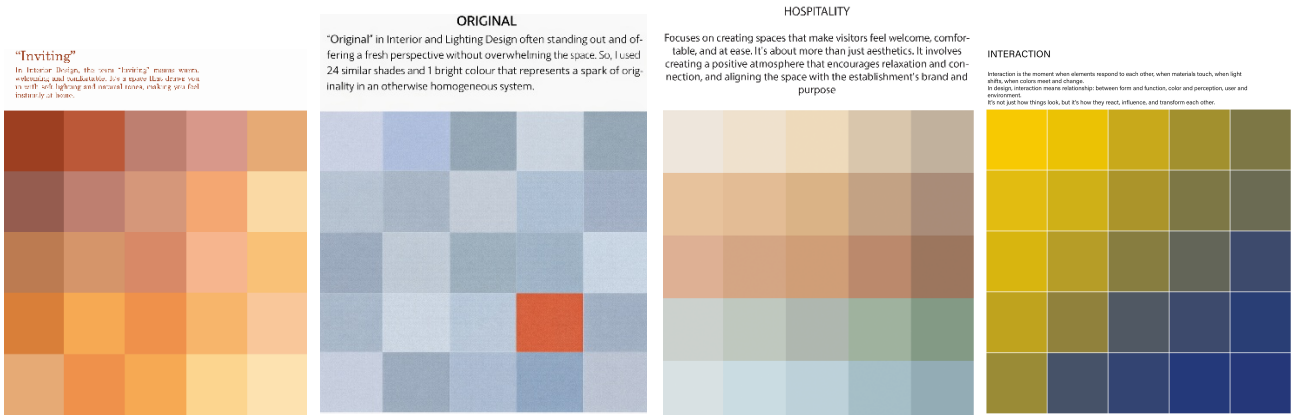

Fig. 1 - Examples of exercises on creating chromatic grids based on words chosen by students. From left to right, the works of *Elisabetta Ampollini, Sara Livio, Anna Locatelli* and *Nicole Volpinari*.

Fundamentals of photometry and lighting design for hospitality

The lessons on the design of light began with a description of the physics of light, followed by a historical account of the steps that led to the modern definition of light as we know it today. In addition to the nature of energy radiation, the fundamentals of photometry have been described: the main light measurement quantities (luminous flux, illuminance, luminous intensity, and luminance) and the basic parameters to be known, such as colour temperature, colour rendering, and the efficiency of lighting sources.

The lesson then moved on to the more practical side: lighting hospitality spaces, with a strong emphasis on hotel lighting design. Numerous examples were presented, and some "tricks of the trade" were seen to illuminate the various areas that generally make up these spaces. Finally, the regulatory aspects related to the lighting of reception facilities were also discussed: the amount of light required for various types of activities, glare containment, and more.

Demonstrations
A number of different optical illusions were demonstrated, focusing on raising students' awareness and attention to detail through observation. The demonstrations are also expected to bring inspiration to students in terms of their creativity and "thinking out of the box". Key takeaway messages from the demonstrations were:

- Negative space (background) can be as functional as positive space (foreground), especially for subliminal influences;
- Beware of ambiguous presentations, such as a single image with two (or more) plausible interpretations;
- Our brain prefers a single unique solution and, therefore, presentation with ambiguity could cause confusion or discomfort;
- Our brain can, and will, also modify information that we perceive to *make sense* for us. An example is our adaptation to changes in light intensity;
- In addition, our brain has the ability to manipulate information to create different or new contexts.

The experience through these demonstrations informed the students that although our visual system receives information about the actual physics of the world, our brain does not necessarily process that information accordingly.

Visual perception
After the students realised that the word as they usually see it is the product of a reelaboration by the visual system (eye, optic nerve and brain), more extensive lectures on the phenomenon of vision took place. These lectures aimed to explain the visual effects observed during the demonstration. They further assist students in developing a deeper understanding of the formation of visual perception and its byproduct, optical illusions. The topics cover:

- Contrast and assimilation - the two commonly found effects, which are both results of the lateral inhibition of the retina influenced by the background of the area of interest, despite being in opposite ways;
- After image - an essential phenomenon that is based on opponency, complementary colours, and the fatigue of photoreceptors in our retina;
- Lighting - not only from the point of view of lighting design and technology, but also the intensity and colour temperature of light sources, as well as their impact on appearance;
- Metamersim - when two material samples match when viewed under one condition but not another; a phenomenon related to spectral power distributions and materials;
- Colour constancy - the ability of our visual system to perceive the approximately same colour of an object regardless of the changes in illumination, attenuating chromatic influence from the light sources;
- Interference of the environment - the surrounding context influences the perception of the observed image, such as the brightness of what we perceive also depends on the background;

- Saccadic eye movements - the ability to perceive contrasts also depends on the involuntary and constant eye movements and results in the visual vibration of static images.

The number of notions related to visual perception was clearly too vast to cover in a short time (Wagemans, 2015). Still, students had been given sufficient competence to start working hands-on with the project. With the theoretical grounding the lecture offers, students were guided to evaluate and appreciate the variety of optical illusion effects and the mechanisms that underpin them.

Identify and Explain

After the theoretical lectures, a task was assigned to the class. In this exercise (named "*Find and Why*"), carried out before the students started working on the projects, involved a hands-on search for and identification of valid optical illusion examples. Students were requested to find valid examples of optical illusions. Drawing on the theoretical content introduced in the lectures, they had to analyse the illusions, identify the observed phenomena, share their findings and explain them, and engage in constructive debate with their peers.

Fig. 2 - Examples of illusions selected as case studies by students in the "Find and Why" exercise. From left to right *Shigeo Fukuda "Images of Illusion 1984 (detail)", Regina Silveira "Abyssal"*, and *Maurits Cornelis Escher "Sky and Water I (detail)"*.

Group Work

After all the alignment lectures were completed, students were distributed into groups and began working actively on the project. A total of twelve groups of three to five students each worked on a project to put their learning into practice through a hypothetical scenario after the conclusion of the 2026 Winter Olympic Games in Italy. The proposed scenario was the requalification of the Olympic village in Predazzo (Trento, Italy). Each group will reimagine parts of the ground-floor interior spaces of the Olympic village, which will be converted into an *optical-illusion-themed hotel*.

Each group selected two spaces for reimaging, with options: two guest rooms, one guest room and the corridor, or one guest room and the hotel reception.

The expected outcome was *to provide users with a distinctive optical-illusion experience while in the spaces*. In addition to the structural areas such as walls, ceiling and floor, students were required to include the furnishings, colour, and lighting details in accordance with the appropriate functions of the spaces. At least one optical illusion principle needed to be demonstrated.

Fig. 3 - Renderings of the pavilion of the Olympic village of Predazzo, whose ground floor was used as a case study. Image courtesy of Archivio Ufficio stampa Provincia Autonoma di Trento.

An unexpected challenge

Optical illusions do not represent failures of the human visual system, but rather reveal the inferential strategies through which perception is constructed (Gregory, 1997). By exploiting prior assumptions and statistical regularities of the natural environment, illusions expose the predictive and interpretative nature of vision, making them a powerful tool for investigating visual perception.
One of the main challenges faced by the students was balancing the experiential potential of optical illusions with the comfort expectations typically associated with hotel rooms. While optical illusions introduce perceptual ambiguity, surprise, and dissonance (Friston, 2010), hospitality spaces require legibility, predictability, and a sense of control to support users' well-being (Mehrabian and Russell, 1974). The design task, therefore, shifted from the mere application of illusionistic effects to the careful modulation of perceptual dissonance.

Balancing these two seemingly irreconcilable aspects proved to be a complex challenge for the various working groups, which ultimately resulted in works that fully embraced the dissonance induced by optical illusions, creating dramatic environments that are intended to be like "*movie sets*" where the user is called upon to live a very peculiar experience, or on the contrary, trying to dilute the bewilderment of illusions into events of more moderate influence, creating welcoming spaces, where illusion is perceived, but not dominant.

Outcomes

The students participating in the Colour Workshop were mainly enrolled in the Bachelor's degree course in Interior Design. The vast majority of groups opted to try their hand at one of the rooms, then chose the corridor and reception as their second spaces. Despite the greater geometric complexity of the reception compared to the corridors, the latter were nevertheless selected in large numbers, probably because of the geometric characteristics that made them ideal for applying solutions that create the typical sense of tension and amazement induced by optical illusions.

The operational work phase of the students lasted for about two and a half days, with back-and-forth revisions with the teachers. Numerous aspects were evaluated during these reviews, including materials, furnishings, feasibility principles regarding optical illusions, and factors related to hospitality lighting. At the end of the workshop, each group presented its work to their peers and visitors in a public presentation of about ten minutes. The projects were laid out on A1 boards and printed for illustration and presentation to the other classes that were tackling the same workshop, but on different aspects of interior design. Given the short time available, the works did not reach the level of executive design; however, their feasibility was verified during the review phase.

Fig. 4 - A complex wall decoration is presented under regular lighting, but the pattern of a specific plant is revealed under different coloured lights. The effect is generated through colour mixing. Project: Chromalusion. Students: Chiara De Gennaro, Gloria Di Gregorio, Giulia Fogli, Alice Livio, Francesca Trevisan.

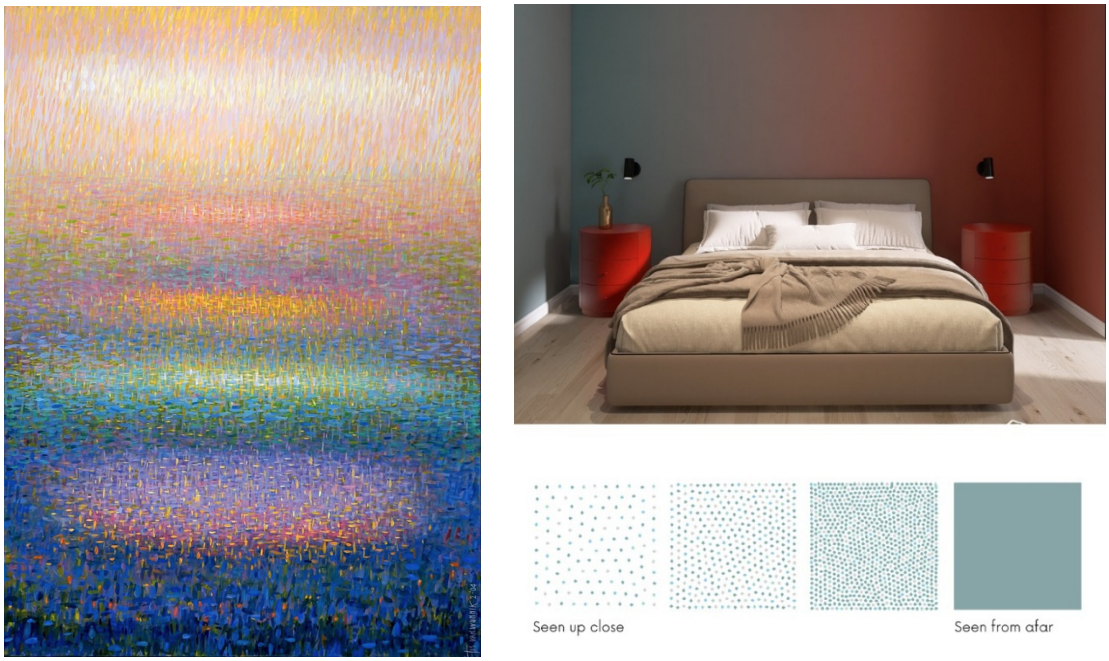

Fig. 5 - The walls of the bathroom seemingly appear to be in solid gradient colours (right). However, when observed closely, the structure of numerous tiny dots is revealed. The effect is generated through pointillism – a result of our eyes being unable to resolve the fine details at a certain level. Project: Deconstruct to Reconstruct. Students: Giulia Artioli, Martina Confalonieri, Francesca Mariani, Davide Ramundo, Chiara Sica

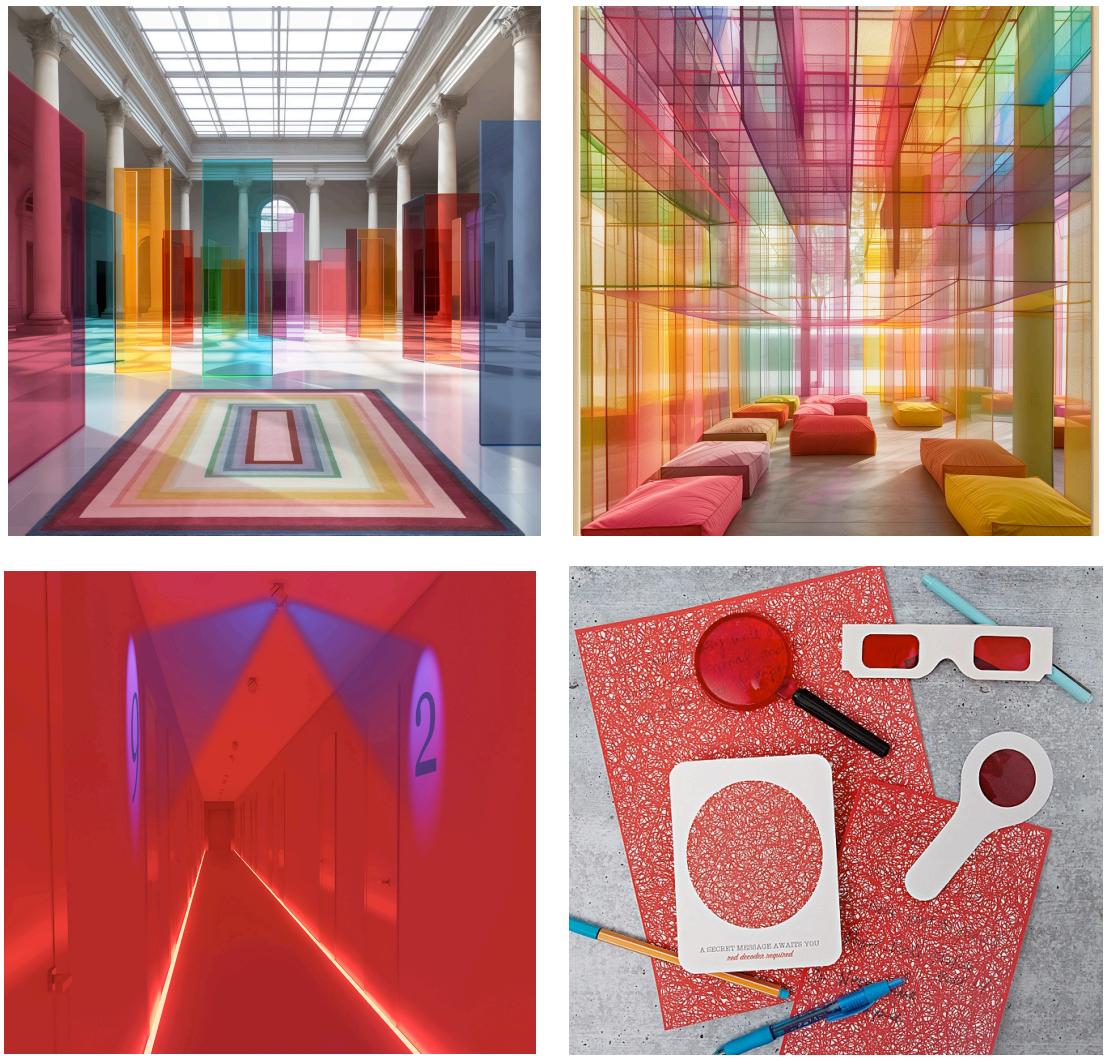

Fig. 6 - Coloured filters are used to reveal or conceal visual elements such as text or graphic shapes. The corridor (below left) employed lighting to simulate a red filter placed over a red illustration with blue text, thereby visually cancelling the red and revealing the blue text. Project: Echo Room. Students: Fabia Elisabetta Ampollini, Sara Livio, Anna Locatelli, Sara Piazzolla, Nicole Volpinari

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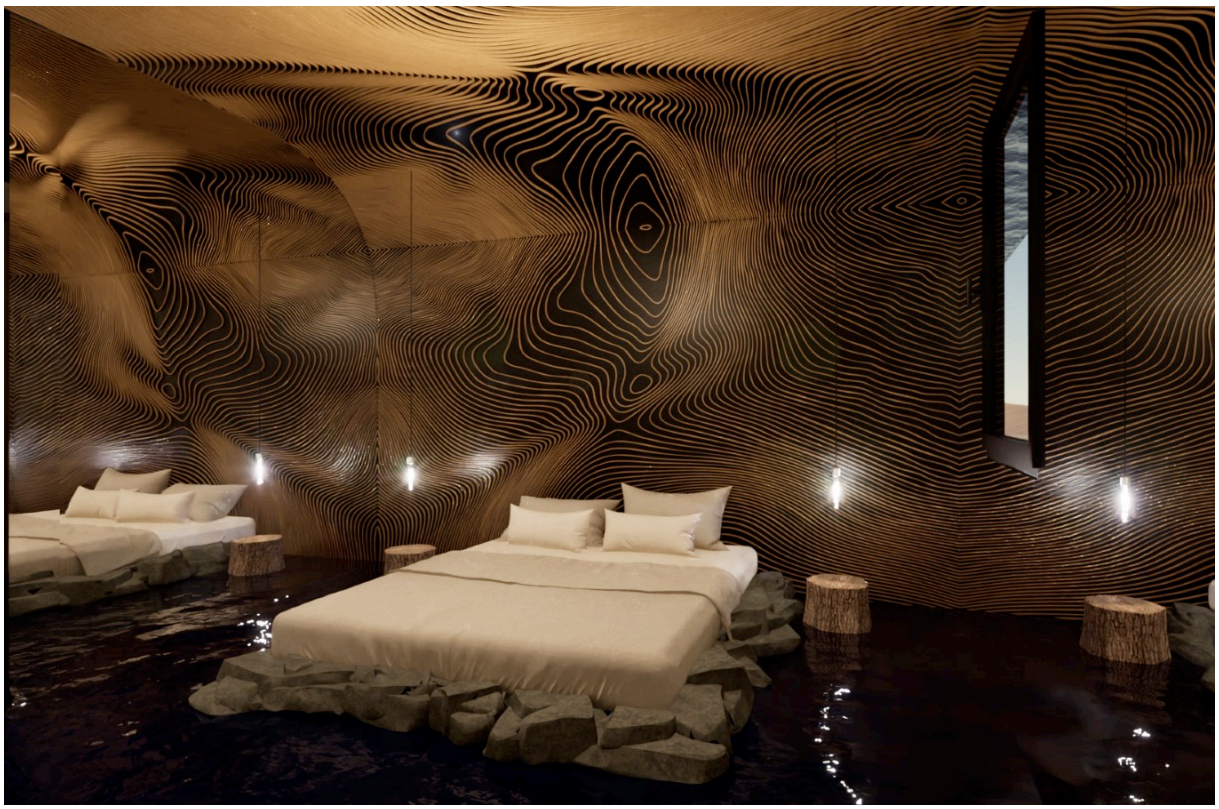

Fig. 7 - The room and corridor offer an immersive journey with natural textures of the Dolomites.The room uses the wood's veins to create an illusionistic effect all over the wall behind the bed, which lies on rocks. Also, mirrored walls offer a broader perspective. Project: The mountain illusion. Students: Benedetta Gagliandro, Michel Guilavogui, Kim Hackmon, Sveva Magatti, Kaisa Vulli.

Conclusions

The Colour Workshop offered an exploration of optical illusions with the aim of generating interest and curiosity in the learning of visual perception. Through the understanding of how visual information is processed and interpreted, more dynamic and engaging environments can be realised. Also trying to find that fleeting balance between the comfort of space and the tension and amazement generated by illusions. Guiding students from observation to identification and analysis, and finally to application, the workshop encourages critical thinking and creative design.

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Cultural harmonies: two CMF workshops on the iconic colors of Friuli Venezia Giulia

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Abstract

This article presents two workshops dedicated to CMF design organized by the Friuli Venezia Giulia Region's Wood, Furniture, and Home System Cluster at the "G. Sello" Art School in Udine and the Bruno Carniello Institute in Brugnera. The workshops, conceived and curated by the author, aimed to teach the fundamentals of color design for the furniture industry and simulate a CMF design project from the concept stage to the prototyping stage, which was carried out in collaboration with companies in the sector. The activity complemented the educational activities of the two institutes and offered the students the opportunity to explore a new approach to color design that promotes a more informed, ethical, and inclusive interpretation of color in products. The CMF design projects included the analysis of the cultural and geographical context and the rediscovery of the region's typical colors, materials, and textures, fostering a deep understanding of the relationship between color and cultural identity. The activity has enabled the implementation of initiatives that enhance the educational activities of the institutes and students' learning paths, providing them with the opportunity to engage with the latest innovations in the field of color design, a crucial phase in furniture product development. Additionally, it has allowed for the development of a replicable design proposal for future editions, with the aim of strengthening a positive contribution to the institutes' offerings and increasing their attractiveness within the industry sector.

Keywords: CMF Design, Cultural Harmonies, Cultural Identity, Iconic Colors, Texture, Tactility, Reuse & Innovation.

Introduction

This article presents two color workshops held in Friuli Venezia Giulia, Italy, in 2024, developed at the request of the Wood, Furniture and Home System Cluster of the Friuli Venezia Giulia Region. The FVG Wood, Furniture and Home System Cluster is a consortium that promotes the development of the furniture sector in Friuli Venezia Giulia, offering services and projects to companies and institutions. The region's furniture industry is concentrated in specialized districts, oriented towards innovation, sustainability, and international markets, and is always seeking qualified technical personnel. The workshops were held at two public schools: the "G. Sello" Art School in Udine and the Bruno Carniello Industrial Professional Institute in Brugnera. The author conceived and curated the workshop content, planning the activities and coordinating their implementation together with the Wood, Furniture and Home System Cluster and the schools' teachers. The courses took place over several months, with scheduled lectures and periods dedicated to project development and prototyping phases.

Objectives and method

The workshops aimed to provide the foundations of CMF design by simulating a real project through all its phases. During the first meeting, dedicated to the project presentation, the basics of color theory, color spaces, and color systems were introduced, along with exercises in both visual and instrumental color measurement, with a focus on the NCS system. Both workshops aimed to guide participants through the final prototyping process, addressing all issues related to the implementation phase. To this end, local companies were involved, engaging with the students and actively participating in the prototype development process.

The most innovative aspect of the courses was the introduction of the concept of cultural harmonies: an approach to color that analyzes the cultural and geographical context of a location, with the aim of rediscovering and enhancing the colors, materials, and textures typical of a specific territory. Cultural harmony is the balanced relationship created between the historical and chromatic identity of a place and the need for innovation in new products. An essential tool for understanding and designing cultural harmonies is the ability to recognize the difference between iconic and syntactic colors. One lesson of the course was dedicated to this topic, addressed interactively through the analysis of colors in the school context.

The first workshop: Liceo Artistico (Art High School) Giovanni Sello (Udine).
The first workshop, "Color Design," was intended for the fourth-year classes of the Architecture, Scenography, and Graphic Design programs at the Giovanni Sello High School in Udine. A total of 80 students from the scenography, graphic design, architecture, and furniture design sections were involved through a multidisciplinary approach, coordinated by the teachers and the project leader. The aim of the project was to innovate the aesthetics of interior surfaces in residential spaces, aligning them with contemporary needs for inclusion and sustainability. The students acquired the knowledge and skills necessary to design a collection of inclusive textures and patterns (fig.1). The theme focused on laminate surfaces, which were meant to narrate the decorative, chromatic, and cultural identity of the Friuli Venezia Giulia region, drawing inspiration from local landscapes, craftsmanship, architecture, and gastronomy (fig. 2/3). The workshop began with a four-hour in-person lecture in Udine, held at the Sello Art High School, and continued over the following months with periodic meetings coordinated by the team of Furniture and Home System Cluster FVG, the class teachers, and the author. During the workshop, 30 surfaces were designed according to the following criteria:

- Inclusion: The surfaces were designed to also be usable through tact by people with visual impairments (partially sighted, blind, or colorblind individuals).
- Sustainability: The materials used were recycled or recyclable, with special attention given to simplifying the production process (cost-effectiveness).
- Aesthetics: The surfaces were created to merge the aesthetic needs of the younger generations with the cultural identity of the local territory. Motifs and textures from the regional culture of Friuli Venezia Giulia were reinterpreted using new technologies (as 3-axis modelling and milling and laser engraving) through a transdisciplinary approach, which included chromatic and material analysis of local dishes.

The project was selected to participate in the second edition of the New European Bauhaus Festival (European Union), organized by the European Commission and presented in a dedicated exhibition at the Innovation Platform in Manzano between April 18 and 20, 2024 (Fig. 4/5).

Figure 1. a) First day of the workshop. b) Survey of project materials.

Figure 2. Experimental phase, creation of a texture with the iconic products of the territory.

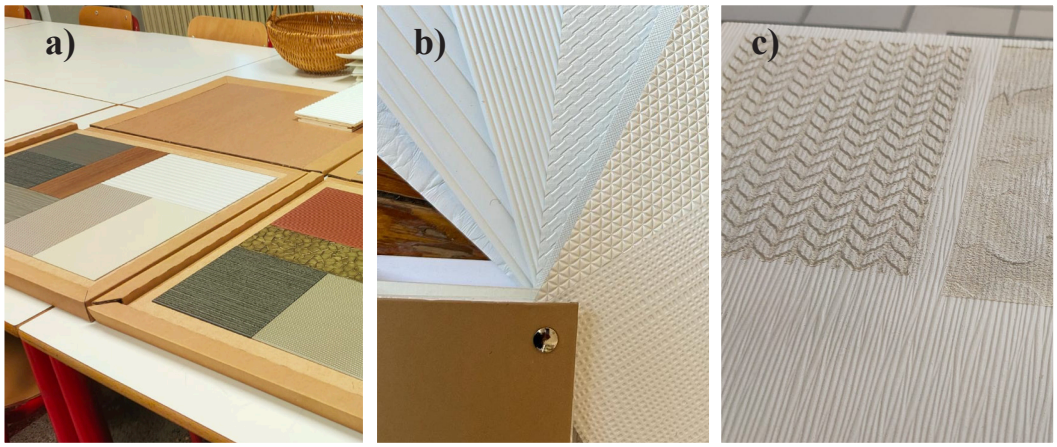

Figure 3. a), b) Examples of tridimensional laminates provided by the sponsors (Hub Finiture PN, Voice Tec, panels for Furnishing TV. c) First samples obtained with laser engraving.

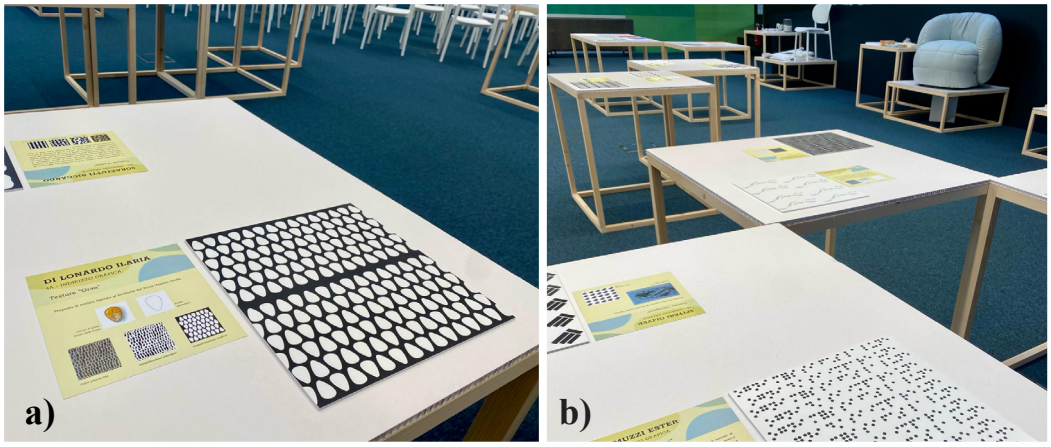

Figure 4. a) One of the final projects. b) Exhibition setup.

Figure 5. Project presentation at the Innovation Platform in Manzano and the event poster

The second workshop: Technical High School Institute Bruno Carniello (Brugnera).
The second workshop took place at the B. Carniello Technical High School Institute in Brugnera, located in the heart of one of the most important furniture districts in Italy and worldwide. The workshop involved fourth-year students from the Interior Furniture and Supplies program as well as the Graphics and Communication course (fig.6). The project focused on the recoloring of worn-out plastic furniture (chairs and tables) used in the refreshment areas of the Pordenone Fiere exhibition center. One of the main goals of the course was to teach students how to reinterpret existing furniture using color and promote the reuse of objects and structures, in compliance with the new Minimum Environmental Criteria (CAM) issued by the Italian Ministry for Ecological Transition (MITE), as stated in the Decree of June 23, 2022, Criteria for energy and environmental sustainability (Italian Ministry for Ecological Transition,2023):

"*CAM promotes eco-design in furniture production by using renewable or recycled materials, modularity, and non-destructive disassembly, enabling the recovery of parts to be reused as replacements or recycled as raw materials.*"

An additional award criterion defined in this decree encourages the reuse, repair, or donation of used furniture. The project also involved the use of iconic colors and decorative patterns from Friuli Venezia Giulia and neighboring regions. The students carried out a color analysis inspired by eight cities: Pordenone, Udine, Gorizia, Trieste, Ljubljana, Treviso, Venice (fig.7), and Spilimbergo (fig.8).

Figure 6. a) Introduction. b) Partner presentation (Colorificio Canton, Verniciatura Corallo).

Figure 7. Recolouring project of worn-out furniture inspired by the city of Venice.

Figure 8. Recolouring project inspired by the city of Spilimbergo.

Once the CMF design phase was completed, the furniture was repainted by a local company specialized in painting plastic furniture (fig.9/10) and later exhibited in Pordenone during SICAM 2024 (International Exhibition of Components, Accessories, and Semi-finished Products for the Furniture Industry, held in Pordenone, Italy) (fig. 10/11).

Figure 9. a) Students visiting the Corallo Verniciatura painting plant. b) Processing stages.

Figure 10. Exhibition graphics installation at Pordenone City Hall during SICAM 2025.

Figure 11. Photos of the event during the presentation and the event poster

Conclusions

This article presented two color workshops held in Udine, Italy, in 2024 and developed at the request of the Friuli Venezia Giulia Wood, Furniture, and Home System Cluster. The author designed and curated the workshops' content, activity planning, and implementation. The first workshop, Color Design, involved fourth-year students from the Architecture, Scenography, and Graphic Design programs at the Giovanni Sello Art High School (Udine). The students developed panels with textures and decorations that express the identity of the Friuli Venezia Giulia region. The selection of the projects for the 2024 New European Bauhaus Festival highlights the originality and quality of the initiative, placing it within an international framework of design innovation.

The second workshop took place at the B. Carniello Technical Institute in Brugnera with fourth-year classes from the Interior Furniture and Supplies and Graphics and Communication programs. The students designed a new visual identity for damaged furniture from the Pordenone Exhibition Center, drawing inspiration from eight cities in and around the Friuli Venezia Giulia region: Pordenone, Udine, Gorizia, Trieste, Ljubljana, Treviso, Venice, and Spilimbergo. The project concluded with the recoloring of the furniture, carried out by a specialized company, and the presentation at SICAM in Pordenone.

The two workshops demonstrated how color can become a powerful tool for innovation, sustainability, and cultural enhancement in the field of design and furniture. Through an approach that combines theory, practical experimentation, and local engagement, students were able to develop concrete skills, experiencing every phase of a CMF design project, from initial research to prototyping. The concept of "cultural harmonies" proved central: analyzing the geographical and historical context made it possible to rediscover the colors, materials, and textures typical of Friuli

Venezia Giulia, integrating them into innovative and inclusive design proposals. The experience encouraged reflection on the relationship between local identity and global trends, offering new insights into contemporary design.
The Friuli Venezia Giulia Wood, Furniture, and Home System Cluster (Cluster Legno, Arredo e Sistema Casa FVG) is a key player in the regional sector, actively engaged in environmental certifications, innovation, business networking, and European projects. Collaboration between schools, institutions, and companies created a replicable model that enriches educational offerings and strengthens ties with the furniture industry. The selection of one of the projects for the 2024 New European Bauhaus Festival and the exhibition of the students' work at SICAM 2024 demonstrate the quality and relevance of the results achieved. This experience highlighted the importance of a design approach that integrates eco-design, inclusivity, and the enhancement of cultural heritage, paving the way for future developments and consolidating the growth of a new generation of designers who are more aware, creative, and sustainable.

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All the teachers of G. Sello Udine
All the teachers of ISIS Carniello Brugnera

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SPECIAL SESSION: Color and Artificial Intelligence

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Authenticity in the Age of AI: Challenges in Colorizing Classic Cinema

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Abstract

As artificial intelligence (AI) tools become increasingly integrated into audiovisual restoration practices, their use raises both technical opportunities and ethical challenges. This study critically explores AI's role in film heritage restoration, with a particular focus on colorization techniques. Drawing on recent literature and case studies, this research highlights the dual imperative faced by audiovisual archives: to enhance the accessibility and visibility of historical materials through digital transformation while safeguarding the authenticity and integrity of original documents. Automated colorization, in particular, has sparked controversy due to its potential to distort historical records and mislead audiences, especially when applied to politically or emotionally charged footage. The study aims to analyse the ethical frameworks proposed to guide such interventions, assess public transparency strategies, and consider how institutions navigate the tension between preservation and innovation. Through this inquiry, we seek to open a broader dialogue on how AI-based media enhancement techniques require careful ethical scrutiny and context-aware application in the stewardship of film heritage.

Keywords: colour in film, cinema, Photography, AI.

Introduction

The rapid diffusion of artificial intelligence (AI) in the field of cultural heritage preservation is reshaping archival and restoration practices in unprecedented ways. Recent international surveys highlight how digitization has become a central activity for archives and audiovisual institutions, motivated by the dual goals of ensuring preservation and expanding accessibility (Bushey, et al., 2025). Within this context, AI emerges as both a powerful enabler and a source of significant ethical and technical challenges. While applications such as OCR (Optical Character Recognition), metadata generation, and speech-to-text transcription are increasingly used to improve efficiency and searchability, the deployment of generative tools for media enhancement, such as automated colorization, raises more controversial questions (Amouroux, 2024).

The transition from analogue to digital has already transformed the audiovisual landscape, shifting from scarcity to an overabundance of content and blurring the boundaries between media producers and heritage institutions. In this new environment, the credibility of archives depends not only on their ability to safeguard fragile originals but also on their role as guarantors of authenticity. AI-driven processes such as colorization, super-resolution, or inpainting, although capable of increasing the visibility of historical footage, risk distorting the historical record if not properly contextualized.

This paper examines the challenges of authenticity in the age of AI, with a specific focus on the controversial practice of colorizing classic photographic and cinematographic film, and it explores how archives balance innovation with ethical stewardship. By situating AI-based colorization within broader debates on digitization, media enhancement, and public trust, the study seeks to outline guiding principles for responsible and context-aware use of AI in film heritage restoration.

AI and the Digitization for Archives

Digitization has become a keystone of contemporary strategies for the preservation and dissemination of documentary heritage. Most institutions in the cultural and archival sectors have undertaken at least one digitization project in recent years, with a strong emphasis on enhancing public access,

safeguarding fragile originals, and increasing institutional visibility. While the majority of digitization efforts focus on traditional practices such as scanning, metadata creation, and digital preservation, the integration of artificial intelligence into these workflows remains at an early but steadily expanding stage.

Survey data (Bushey, et al., 2025) show that digitization is widely regarded as essential for both preservation and access. Institutions consistently identify increasing public access and improving research opportunities as their primary motivations for digitization, followed closely by the conservation of originals and the mitigation of risks related to technological obsolescence. At the same time, the process is resource-intensive, demanding substantial financial investment, skilled personnel, and robust digital infrastructures. Challenges such as limited funding, staff shortages, and insufficient institutional support emerge as recurring obstacles (Ruivo, et al., 2018), (Plutino, 2024). These structural constraints are directly relevant to the discussion of AI integration, as one of the main promises of AI tools lies in their ability to reduce labour demands and streamline repetitive tasks.

Despite the growing discourse around AI, the actual deployment of AI tools in digitization projects remains limited. Fewer than one-third of institutions surveyed reported having experimented with AI, and when used, AI was most frequently applied to tasks such as optical or handwritten text recognition (OCR/HTR), speech-to-text transcription, and metadata generation. These applications are aligned with core archival needs: they enhance the searchability, discoverability, and accessibility of digitized collections. However, such uses are primarily supportive rather than transformative, complementing existing workflows rather than redefining them.

In (Bushey, et al., 2025), when institutions did consider the risks of AI, concerns clustered around ethical and epistemological issues, respondents pointed to biases in training datasets, lack of transparency in algorithmic decision-making, and potential distortions introduced by automated processing. While only a minority of organizations had formally identified risks, the responses suggest a growing awareness that AI adoption cannot be limited to technical considerations alone. Questions of accountability, accuracy, and authenticity are increasingly recognized as critical to maintaining institutional credibility, especially in the cultural heritage domain, where the integrity of records is paramount.

In this context, AI is primarily envisioned as a means to alleviate bottlenecks in current workflows. Still, the survey revealed limited attention to the broader ethical implications of AI, suggesting that systematic frameworks for evaluation and governance are still underdeveloped. In sum, the integration of AI into digitization projects highlights a paradox: while the technology is celebrated for its potential to expand access and efficiency, its adoption remains modest, fragmented, and often experimental. Institutions recognize that AI cannot substitute the professional judgment of archivists, conservators, and researchers, but instead must operate in conjunction with human oversight. As digitization continues to scale and diversify, the role of AI will likely expand, making it imperative for cultural heritage institutions to develop not only technical capacity but also ethical and organizational strategies to guide its responsible use.

Colorization as a Critical Case Study

Among the many applications of artificial intelligence in audiovisual archives, colorization stands out as one of the most debated. Unlike tasks such as metadata creation, transcription, or quality control, colorization directly reshapes the visual appearance of historical documents. By altering black-and-white footage, AI-driven colorization does not simply add information but transforms the interpretive frame through which audiences perceive the past. This capacity to fundamentally reconfigure historical imagery makes colorization a particularly sensitive and controversial intervention.

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The practice of colorizing films and archival footage has a long history, evolving from philosophical and legal disputes in the 1980s to contemporary discussions framed by artificial intelligence and digital heritage ethics.

The first wave of controversy emerged in the late 1980s, when technological advances enabled manual and semi-automated colorization of black-and-white classics. Scholars argued that objections to colorization could be grouped into three domains: respect for creative intention, the integrity of the artwork, and the quality of audience experience (James, 1989). Philosophers and film theorists questioned whether transforming black-and-white works into colour violated the original artistic vision or diminished their expressive force (Leibowitz, 1991); in parallel, legal scholars explored whether colorization infringed moral rights and copyright, especially in cases where directors or their estates opposed such transformations (Wagner, 1989). This early period established the ethical and aesthetic concerns that continue to shape the debate today.

As digital technologies advanced, colorization became less labour-intensive and more visually convincing. Techniques based on convolutional neural networks (CNNs) and large training datasets allowed for semi-automated approaches, often marketed as "restoration." Research during this period investigated how machine learning could improve colorization accuracy, especially when applied to historical photographs and films. Yet technical studies also highlighted persistent challenges: the reliance on biased datasets, the tendency to impose anachronistic palettes, and the limited ability to reproduce the material texture of early cinema (Sanae & Besserer, 2020). Despite these limitations, the cultural industry increasingly embraced colorized versions of archival material for television, streaming platforms, and popular documentaries.

In the last decade, colorization has re-emerged with new intensity, driven by advances in AI and the appetite of audiences for emotionally engaging historical narratives. High-profile productions such as They Shall Not Grow Old (2018) or the colorized Warsaw Uprising documentary (1944) have popularized the technique, framing it as a way of "bringing history to life". At the same time, scholars have critically examined the epistemological consequences of such practices. Analyses of war documentaries argue that AI-based colorization risks transforming historical testimony into affective spectacle, obscuring the critical distance required for historical understanding (Simor, 2025). Other works, frame colorization within a broader cultural trend of "technostalgia", suggesting that the desire for color has been normalized as a benchmark of realism, highlighting how digital technologies foster a fantasy of immediacy that effaces the historical texture of images, producing a confusion between authenticity and simulation (Habib, 2025). A recent case study on the AI-based colorization of Satyajit Ray's Pather Panchali (1955) demonstrates how symbolic the addition of artificial colour can significantly diminish depth and emotional resonance, as experts consistently emphasized the loss of cinematic symbolism and authenticity in the colorized version (Tanmay & Rawat, 2024).

Recent literature converges on the recognition that colorization is not a neutral technical enhancement but a transformative intervention with ethical implications. Key concerns include: (1) the risk of misleading audiences, (2) the erasure of the original filmic context, and (3) the reinforcement of cultural biases embedded in AI training sets. At the same time, advocates point to the potential of colorization to expand public access, revitalize interest in archival collections, and engage new generations with audiovisual heritage. This duality underscores the central tension in current debates: balancing innovation and accessibility with the obligation to preserve authenticity.

Today, colorization functions as a benchmark for broader discussions on AI in film restoration. Colorization shows both the opportunities and the risks of AI in media restoration, making clear the need for ethical rules. The main principles are transparency (telling viewers when material has been altered), contextualization (adding historical explanations), and keeping access to the original version. These steps are seen as essential to protect the credibility of archives in a time when audiences expect digitally enhanced images.

In summary, the state of the art shows a long-standing oscillation between enthusiasm for the aesthetic and commercial potential of colorization and concern for its ethical and historical consequences. With the rise of AI, the debate has intensified, making colorization a paradigmatic case through which the cultural sector negotiates the future of authenticity in the digital age.

Towards Ethical Frameworks for AI in Film Restoration

The integration of AI into film restoration and reediting is not only a technical challenge but also an ethical and cultural one. As generative and enhancement tools become more widely used, the urgency of clear frameworks to regulate their application in heritage contexts has increased. Film archives and cultural institutions, traditionally entrusted as custodians of authenticity, now face the challenge of balancing their preservation mission with the pressures of technological innovation and the demand for engaging digital content.

A first principle is transparency. Whenever AI is used to modify or enhance audiovisual materials, institutions should disclose the nature and scope of the intervention. This may involve labelling modified sequences, providing documentation of the processes involved, and ensuring that audiences always retain access to the original version. Initiatives such as the Content Authenticity Initiative (CAI) (Adobe, 2024), developed in collaboration with the Coalition for Content Provenance and Authenticity (C2PA) (Coalition for Content Provenance and Authenticity, 2025), provide concrete models for ensuring transparency. Through the C2PA Content Credentials standard, they create open tools to embed and verify provenance information directly in digital content, allowing users to trace modifications and authorship. Applied to audiovisual heritage, such mechanisms help safeguard trust, prevent misinterpretations, and ensure that AI-based interventions remain visible and accountable.

Equally important is contextualization. AI-driven enhancements, especially colorization or reconstruction, should be presented with historical and scholarly commentary that situates them in their cultural, political, and social contexts. This prevents distortion and fosters critical engagement, particularly in the case of sensitive or contested footage where even minor alterations may significantly influence interpretation.

Another essential dimension concerns authorship and moral rights. Original creators and rights holders retain claims over the integrity of their works. Any AI-based modification, whether adding colour, altering frame rates, or reconstructing missing segments, should respect these rights, seeking consent where possible and always acknowledging the intentions and legacy of the original creators.

Frameworks must also account for bias and algorithmic opacity. AI systems are trained on datasets that may carry cultural, racial, gender, or geopolitical biases, which can inadvertently shape outputs and distort historical realities. Human oversight, quality control, and transparent evaluation of algorithmic performance are necessary to counter these risks. Groups such as the DOAWG (Digital Object Authenticity Working Group, 2025) are already working to develop guidelines and methodologies that prioritize the protection of original archival materials, setting limits on alteration practices and ensuring that preservation remains central.

At a broader level, institutional responsibility is fundamental. Archives and cultural organizations should adopt policies that explicitly define their position on AI in restoration, aligning with international ethical recommendations and sector-specific initiatives. These policies should not only address accountability and consistency but also consider sustainability, given the environmental costs of large-scale AI computation.

Finally, public engagement is key. In a media landscape dominated by streaming platforms, social networks, and immersive exhibitions, fostering media literacy is crucial. Educating audiences about the difference between original and altered materials, and inviting dialogue around these practices, strengthens trust and positions institutions as transparent mediators rather than gatekeepers.

In conclusion, moving towards ethical frameworks for AI in film restoration requires a multifaceted approach: transparency, contextualization, respect for authorship, vigilance against bias, robust institutional policies, and active public participation.

Conclusions

The analysis presented in this paper has highlighted the complex interplay between technological innovation and historical authenticity in the field of audiovisual restoration. Artificial intelligence offers new possibilities for access, visibility, and engagement with archival materials. Yet, these opportunities come with significant risks when interventions such as colorization alter the meaning, symbolism, and expressive depth of original works.

Colorization exemplifies the ambivalence of AI-driven restoration: while it can attract new audiences and revitalize interest in cultural heritage, it also challenges the integrity of historical records and raises questions of authorship, moral rights, and institutional credibility. The case studies and scholarly debates examined show that colorization is not a neutral enhancement but a transformative act that requires careful ethical scrutiny.

To navigate these tensions, archives and cultural institutions must adopt responsible frameworks that emphasize transparency, contextualization, respect for creators' intentions, and vigilance against algorithmic bias. Initiatives such as the CAI and the DOAWG demonstrate that standards for provenance, authenticity, and accountability can be developed and applied in ways that strengthen public trust.

Looking forward, the challenge will be to harmonize innovation with preservation by building shared standards, best practices, and policies that ensure both the protection of originals and the critical engagement of audiences. Public awareness and education will be essential in this process, helping viewers to understand the difference between authentic documents and AI-mediated reinterpretations. Only through such comprehensive strategies can film archives ensure that AI remains a tool for preservation and accessibility without compromising authenticity, integrity, and cultural memory.

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