Color Culture and Science
Cultura e Scienza del Colore

CCSJ

Volume 16

Number 2

2024

ISSN

2384-9568

COLOR CULTURE AND SCIENCE Journal
CULTURA E SCIENZA DEL COLORE
CCSJ
jcolore.gruppodelcolore.it
ISSN 2384-9568
DOI: 10.23738/CCSJ.00
ANCE: E227716
Registrazione Tribunale di Milano n. 233: 24/06/2014
ANVUR Agenzia Nazionale Valutazione sistema Universitario e Ricerca
APeJ Academic Publications eJournal
BASE Bielefeld Academic Search Engine
DBH Database for statistikk om høyere utdanning
DOAJ Directory of Open Access Journals
EZB Elektronische Zeitschriftenbibliothek Regensburg
JURN Search tool for open access content
ROAD Directory of Open Access scholarly Resources
SCOPUS
ZDB Zeitschriftendatenbank

Volume 16, number 2, December 2024
DOI 10.23738/CCSJ.160200

PUBLISHER
Gruppo del Colore – Associazione Italiana Colore
www.gruppodelcolore.org
Registered office: Piazza Carlo Caneva, 4 - 20154 Milan (IT)

PEER REVIEW PROCESS

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

First review level

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

Second review level

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

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

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

TOPICS

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

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

Table of Contents

Editorial. Color Dynamics in Cultural Heritage: Scientific Perspectives and Insights

Dear readers,

The vibrant field of color science in cultural heritage, spanning materials analysis, color perception, and conservation strategies, enriches our understanding of cultural heritage and its degradation processes due to their intrinsic properties and the influence of environmental parameters. In this special issue titled Color Dynamics in Cultural Heritage: Scientific Perspectives and Insights, a collection of diverse, methodologically rigorous studies uncovers the many facets of color's role in interpreting and preserving cultural heritage. This compilation brings together case studies, technical studies, and the development of innovative imaging techniques, presenting both theoretical and practical advancements that bridge art history, materials science, and conservation.

In this issue, several themes emerge, each shedding light on different aspects of color in heritage conservation. For instance, studies on architectural heritage explore how environmental factors and material degradation impact color stability in buildings and monuments. These papers emphasize the importance of contextual sensitivity in preserving immovable heritage, as colors in architectural elements often face unique challenges due to prolonged exposure to sunlight, pollution, and moisture. Techniques such as colorimetry and visible spectroscopy are applied to monitor and analyze color stability, providing insights into how environmental conditions affect color perception over time. In contrast, a second group of papers focus on movable heritage often examining color in terms of more contained environments, such as museums or controlled storage conditions.

In the first paper, **Lhi and Choi**'s study on the Ten Symbols of Longevity in Korea's late Joseon Dynasty presents a compelling picture of socio-political influences on artistic color choices. Here, the transition from traditional to Western synthetic pigments reflects shifting Confucian values toward a more vivid color palette, allowing new interpretations of cultural identity through color. This case provides a historical grounding for the transformations explored throughout the issue, illustrating the societal impact on materials and pigment selection.

Reichold and colleagues delve into the influence of varnish on color perception through a comprehensive study of Vasari's Resurrection of Christ and Saints. Their investigation on varnish deterioration emphasizes how subtle environmental factors can significantly alter the original appearance of artworks over time. This precise, non-invasive approach in monitoring varnish brings forth challenges relevant to the studies on long-term color change and preservation in historical artifacts. This is related to the goal of the paper by **Thickett et al**., which presents an examination of the effects of natural light aging on actual museum objects. The authors propose a methodology that combines light levels monitoring in exhibition spaces together with spectrocolorimetric mesurements conducted on cultural heritage objects over a large time span of up to 70 years depending on the type of object evaluated.

Llácer-Peiró et al.'s optical analysis of cobalt blue pigment in oil painting aligns well with the detailed case of grisaille glazing by the same research team, which examines how underlying grayscale layers influence the final appearance of painted glazes. Together, these studies reveal the technical nuances in creating and conserving multilayered paint systems, with the microscopic analysis of aging pigments shedding light on how artists used color layering to achieve depth and luminosity. This is a theme echoed in **Perondi**'s paper on the chromatic image method. Perondi's method offers a novel tool for visualizing subtle hues, enhancing conservators' capacity to understand cultural heritage objects, while allowing to capture essential details for making informed conservation treatments. The author demonstrates that the method is effective in revealing details in shadowed areas, enhancing the readability of drawings, and aiding in the identification of damage areas.

Moving beyond traditional conservation, **Pylypchuk**'s study addresses color perception in interior spaces, exploring how color choices affect the ambiance and functionality of designed spaces. The author defined three levels of color perception, namely maximum, intermediate, and minimum. They depend on various factors such as degree of color contrast, combinations and connections of colors, and signs of associative color scheme. The developed method serves to create a balance between the color of art objects and the interior space. This approach contrasts with **Odetti and co-authors**' research on chromatic interventions in public spaces, which focuses on the role of color as a cultural unifier and identity marker in urban heritage conservation. These studies underscore how color theory and perception extend from object-focused heritage to broader spatial and social applications, further integrating community and conservation.

The paper by **Muñoz-Alcocer et al**. explores color matching in polychrome wooden ceilings through the combination of scientific analysis and hands-on conservation, offering an approach for matching historical colors using the sottotono technique. This sensitive approach respects the historical integrity of Spanish colonial art while addressing the complexities of color fidelity and variation—a theme that finds resonance in **Medeiros and da Silva**'s work on colorimetry in heritage tile conservation. By applying rigorous colorimetry standards, Medeiros and da Silva demonstrate the effectiveness of scientific collaboration in conserving architectural elements, echoing the emphasis on color consistency and respect for original hues.

Finally, **Catella**'s analysis of polychrome surfaces in Apulia highlights color's symbolic role in architectural identity. Through the evolution of neo-medievalism, color emerges not only as an aesthetic choice, but also as a vehicle for regional and national identity. This ideological role of color in heritage resonates with Odetti et al.'s work in urban revaluation, both studies affirming how chromatic choices influence collective memory and historical interpretation.

In summary, Color Dynamics in Cultural Heritage presents a comprehensive view of how color is studied, preserved, and interpreted within the diverse context of cultural heritage. By examining both movable and immovable objects, this issue emphasizes the shared challenges and distinct approaches in the conservation and preservation of color. The articles collectively demonstrate the importance of scientific precision in monitoring color changes, while also addressing the interpretive role of color in engaging audiences with cultural heritage objects. Through these contributions, the issue underscores the vital role of color in preserving cultural continuity, inspiring ongoing research that bridges art, conservation, science, and heritage for future generations.

We extend our gratitude to the researchers and conservation professionals whose work graces this special issue, advancing our collective understanding of color in cultural heritage. Through their studies, we gain a more nuanced appreciation of the ways color preservation supports our cultural continuum, safeguarding the stories and memories that color brings to life.

Sincerely,

November 2024

Julio M. del Hoyo-Meléndez[1] and Marcello Picollo[2]

[1] Head of the Laboratory of Analysis and Non-Destructive Investigation of Heritage Objects
The National Museum in Krakow
30-062 Krakow, Poland
jdelhoyo@mnk.pl
[2] Senior Researcher at the Istituto di Fisica Applicata "Nello Carrara" del Consiglio Nazionale delle Ricerche
50019 Sesto Fiorentino, Florence, Italy
m.picollo@ifac.cnr.it

Colour Change of The Ten Symbols of Longevity in the Late Joseon Dynasty

Lhi, Wona[1], Choi, Gyoungsil [2]

[1] *Department of Colour Design, Ewha womans University, Seoul, Korea. nekolhi@ewhain.net*

[2] *Department of Colour Design, Ewha womans University, Seoul, Korea. gschoi@ewha.ac*

Corresponding author: Choi, Gyoungsil (gschoi@ewha.ac)

ABSTRACT

The Ten Symbols of Longevity (*Sibjangsengdo*) is an auspicious painting that expresses wishes for long life and wealth. The origin of *Sibjangsengdo* is unknown, but the literature suggests that it has been passed down as a custom of *Sehwa* (paintings given to subjects at the beginning of the year by a king) since the end of the *Goryeo* Dynasty (14C). Most of the extant *Sibjangsengdos* were painted in the late *Joseon* Dynasty (18C-19C). The paintings of the early *Joseon* Dynasty (14C) were based on the tradition of *Goryeo* painting and combined with the unique aesthetics of the *Joseon* Dynasty, but due to the Neo Confucian attitude to life, which was the founding principle of the *Joseon* Dynasty, the paintings were restrained in their expression of colour. However, in the late *Joseon* Dynasty, changes in social ideas such as *Silhak* (Realist School of Confucianism) led to a different colour change. The purpose of this study is to examine *Sibjangsengdo* Paintings, known as 'Type 1', 'Type 2', and 'Type 3' in art history, from the perspective of *Silhak* and the resulting changes in pigments. Type 1 is the oldest of the four. Type 2 is Western-influenced and uses Western synthetic blue and green. Type 3 is much different in composition and colouring from Type 1 and Type 2, with the colour of blue being distinct. The colours of the digitised symbols of each type of *Sibjangsengdo* were estimated using the NCS index. The RGB and L*, a*b*, and C* values of the colours were estimated using CIELAB. With the collapse of the ruling hierarchy in the late *Joseon* Dynasty, paintings by Court Painter were also decorated in the dwellings of the common people, and as Western synthetic pigments replaced traditional pigments, the restrained colours of the paintings gradually gave way to more saturated colours due to the diversity of pigments, especially in the blues and greens. Azurite and malachite were replaced by Western synthetic pigments such as Prussian blue and emerald green, which produced more vibrant colours than in previous paintings.

KEYWORDS The Ten Symbols of Longevity *(Sibjangsengdo*), Colour change, Neo-Confucianism, *Silhak* (*Realist School of Confucianism*), Western artificial pigments, vivid

RECEIVED 24/07/2024; **REVISED** 08/08/2024; **ACCEPTED** 02/09/2024

1. Introduction

1.1 *Background and purpose of the study*

The Ten Symbols of Longevity (*Sibjangsengdo*) is a painting that depicts the desire for a long life. It has been the main subject of *sehwa* (paintings given by kings to their subjects at the beginning of the year) since the middle of the Joseon Dynasty. The ideological background of *Sibjangsengdo* was Taoism, a religion that promoted longevity. In court ceremonies and real life, Joseon looked to the mythical ideals of Taoism and Buddhism for royal security and the perpetuation of power, but the dominant ideology was Neo-Confucianism. The early Joseon Dynasty inherited the brilliant colours of Goryeo and Chinese painting but gradually became more subdued and restricted in the use of colour as the founding philosophy of neo-Confucian values was emphasised. However, in the later *Joseon Dynasty*, the influence of *Shillhak* led to the development of commerce, the formation of social capital, and the dismantling of the hierarchy, which encouraged the common people to take an interest in painting. As a result, the common people began to become the main agents of reception and production. At the same time, functional paintings by court painters also came to decorate the living spaces of the common people. The colour expression of religions such as Buddhism and Taoism, which had been practised since before the *Joseon* Dynasty, began to recover. *Sibjangsengdo*, which inherited the traditional techniques and styles of *Dohwaseo* (a government office that drew pictures required by the state during the Joseon Dynasty), also experienced changes in colour over time, just like general paintings.

To date, there has been a lack of specific colour analysis studies on these *Sibjangsengdos*. Based on previous research (Park, 2018), three representative types are known to the academic community among the extant late Joseon *Sibjangsengdos*. This study is about the changes in the composition and colour of *Sibjangsengdo* due to the emergence of *silhak* in the late Joseon Dynasty.

2. Types, components and pigments

2.1. *Types of Sibjangsengdo*

Joseon paintings are roughly divided into the early period (1392-1550), the middle period (1550-1700), the late period (1700-1850), and the final period (1850-1910) according to stylistic changes. The late *Joseon Sibjangsengdo* are divided into three types (See Figure 1). according to their pictorial characteristics (See Table 1). Type 1 is a relatively early form and reflects the characteristics of court painters in the middle *Joseon* Dynasty. The colours are less light and saturated than the other types. In the composition, the expression of waves is emphasised, cranes are represented only by white cranes, and white deer are also found only in this style. Type 2 is a typical *Sibjangsengdo* from the late *Joseon* Dynasty. Influenced by Western painting methods, it has a sense of space and perspective and is characterised by strong colouring with higher lightness and saturation than Type 1.

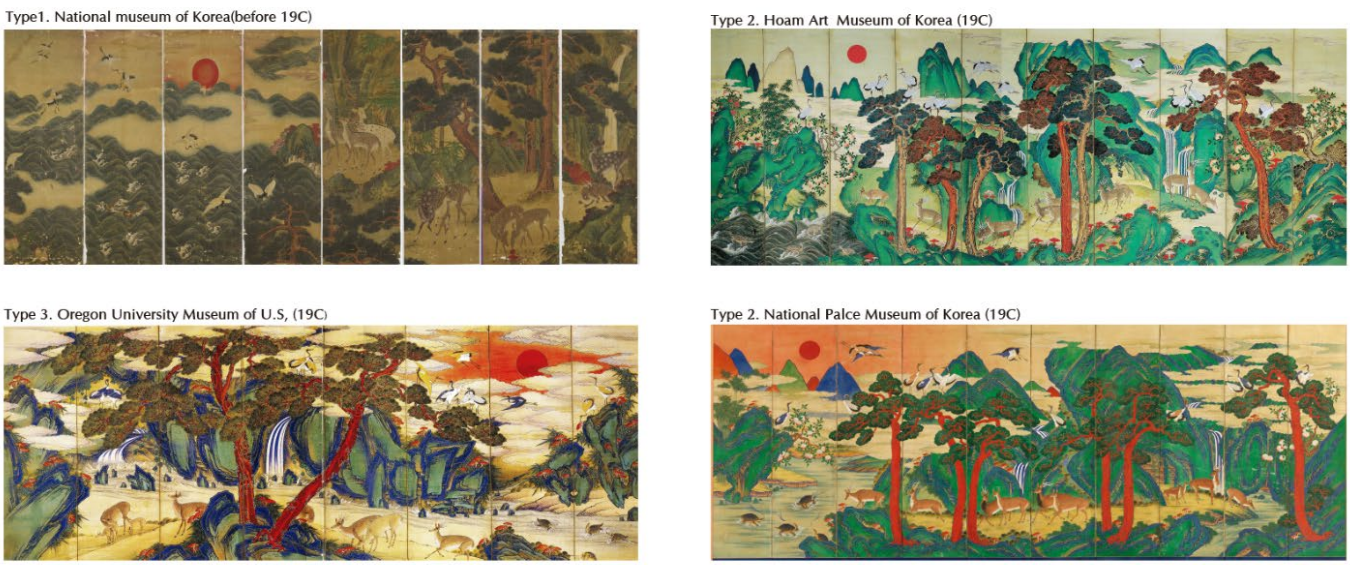


Fig. 1. Sibjangsengdo by Types. "This work was created by 'National Palace Museum of Korea' and used the 'Sibjangsengdo Folding Screen', which is open to the public as a type 1 public domain, and can be downloaded for free from 'National Palace Museum of Korea, https://www.emuseum.go.kr'. https://www.gogung.go.kr/"

	classification	Type1(unknown)	Type 2 (unknown)		Type 3(1880)
characteristics	possession	National Museum of Korea	Hoam Museum of Art(**H**)	National Palace Museum(**N**)	Oregon Univ. Museum of Art Collection, U.S.A.
	wave	Prominence	diminished	disappeared	disappeared
	peach	week expression	emphasised	emphasised	disappeared
	white deer	white deer	disappeared	disappeared	disappeared
	crane	white crane	white crane, blue crane, yellow crane	white crane, blue crane, yellow crane	white crane, blue crane, yellow crane
	colour	vert-blue	blue-green	increased use of blue	a deep blue
	tone	dark greyish,	deep	strong	vivid
	composition	Three god mountain	High mountains and deep valleys	High mountains and deep valleys	High mountains and deep valleys
	perspective		○	○	
	pigment	Malachite, azurite	Prussian blue	Malachite, Emerald green, Prussian blue	Malachite, Emerald green, Prussian blue

Tab. 1. Changes to the composition of Sibjangsengdo (Park, 2018).

It is dominated by greens and blues. There are three types of cranes: white cranes, blue cranes, and yellow cranes. Type 3 is the only one that can be dated (1800). The peach disappears and the rock colour is a reddish blue.

The important symbols of *Sibjangsengdo* are the sun, rock, crane, deer, bamboo, pine, *yeongji* (reishi mushrooms), and peach, with colour changes depending on the form (See Figure 2). The meaning of ten is not the meaning of a number, it has connotations of 'completeness', 'fullness', 'infinity', and 'eternity' throughout Eastern cultures.

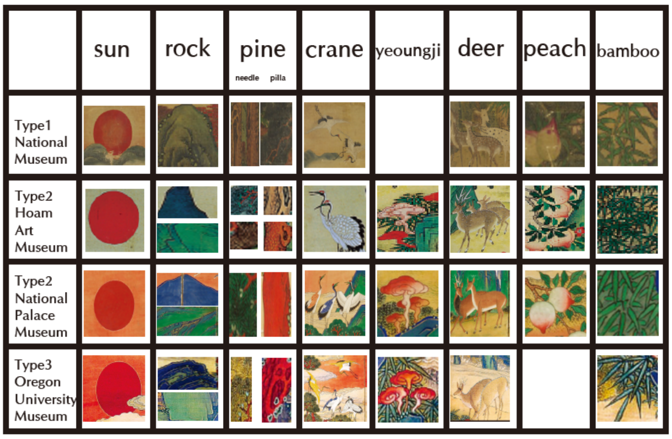


Fig. 2. Color changes of 8 important symbols.

Qin Shi Huang (the first emperor of China), who unified China in 221 BC, had over 3,000 concubines and was wealthy, but not immortal. He sent people to Korea and Japan because he heard that an island in the East Sea had a "magical mushroom" that, if placed on the face of a dead person, would bring them back to life. The mushroom mentioned in this story is the reishi mushroom. It's also said that the secret to *Yang Guifei's* (*Guifei* being the highest rank for imperial consorts during her time the fourth most beautiful woman in China, consort of the *Tang* Dynasty's Emperor *Xuanzong*) transformation into a beautiful woman was eating reishi mushrooms.

2.2. *Characteristics of pigments*

From ancient times to the late *Joseon* Dynasty, about 30 natural pigments were used in paintings, including malachite, azurite, jinsa, artificial pigment vermilion, and natural dyes. The mineral pigment malachite ranges from L*44.61 to 78.08, a*-19 to 40, and b*6 to 16 (Park, et al., 2015). Azurite is L*39.28, a*-2.97, b*-37.29 (Park, et al., 2023). The middle *Joseon* Dynasty was a time of recovery from war and frequent civil disturbances; however, natural pigments were scarce and could not keep up with the demand, so a mixture of dyes and traditional pigments was used. In the late *Joseon* Dynasty, western synthetic pigments such as emerald green and Prussian blue gradually began to be used. The greens became more vivid and the blues changed the angle of the colour from greenish blue to reddish blue (Lhi, 2024). Synthetic pigments were more saturated than traditional pigments and had better colour rendition and chromogenicity. They were widely used because they were less prone to cracking or peeling, not difficult to colour, and inexpensive. Western synthetic pigments gradually replaced traditional pigments (especially green and blue), and the traditional pigments of black, white, and red were used alongside other imported pigments.

2.3. *Joseon's social thought and colour painting*

The highly colourful Bukjonghwa (Northern landscape style) style was popular in the early Joseon Dynasty but gradually lost ground to Confucianism. However, the middle Joseon Dynasty paintings were painted in ink, avoiding colour, to emphasise the purity, virtue and steadfastness of the *Seonbi* (They were scholars during the *Goryeo* and *Joseon* periods of Korean history.). The middle period of the *Joseon* Dynasty saw the height of Neo-Confucian aesthetic thought, which valued simple beauty as a virtue. Court paintings that emphasized colour were downplayed, and decorative paintings such as *Sehwa* were no longer produced. Buddhist paintings were also devoid of colour, with many line paintings being produced. As in the previous period, black-and-white ink paintings dominated, with colour being excluded throughout. In the Late *Joseon* Dynasty, colour expression became freer and richer due to the decline of Neo-Confucianism, the influence of pragmatism, and the importation of Western pigments. *Minhwa* (Korean folk paintings), the coloured paintings that emerged in the late *Joseon* Dynasty, also used bright colours based on symbolism, and brilliant colours became common.

3. Colour analysis method

3.1. *Data and analytics*

This study was based on a previous study (Park, 2018) that analysed *Sibjangsengdo* by types (See Table 1).

3.2. *Analysis method*

The colour analysis method is as follows.

a. Estimate the colours of each symbol in the digital material of the four *Sibjangsengdos* (Type1, Type2 H, Type2 N,, and Type3) using the NCS index.
b. Get the RGB values of the estimated colours.
c. Get the L*, a*b*, C* values.
d. Plot the L*, C* and a*b* graphs to analyse the chromaticity.

4. Colour analysis results

4.1. *a*b*graphs of Sibjangsengdos* by types

There are a*b* graphs of each type (See Figure 3).

There are a*b* graphs of rocks and pines (See Figure 4):

a. Rock -They are coloured with blue overlaid on green rocks.
   -Green rocks - Based on Type 1, the green becomes more saturated in Type 2 and then desaturates again in Type 3.
   - Blue rocks - Blue rocks appear in Type 2, and the blue rocks in Type 2 and Type 3 are blue with a reddish tinge.
b. Pine tree

   The colour of the pillars of Type 1 is the standard.

   -Type 2 H is more yellow, with more saturated brown and orange colours.

   -Type 2 N is more saturated and reddish than Type 1.

   -Type 3 is also more saturated and red than Type 1, but less saturated and less light than Type 2.

   The colour of pine needles of Type 1 is the standard.

   - Type 2 H has changed to yellow and blue. Type 2 N is a more saturated green colour. Type 3 has a more yellow colour.

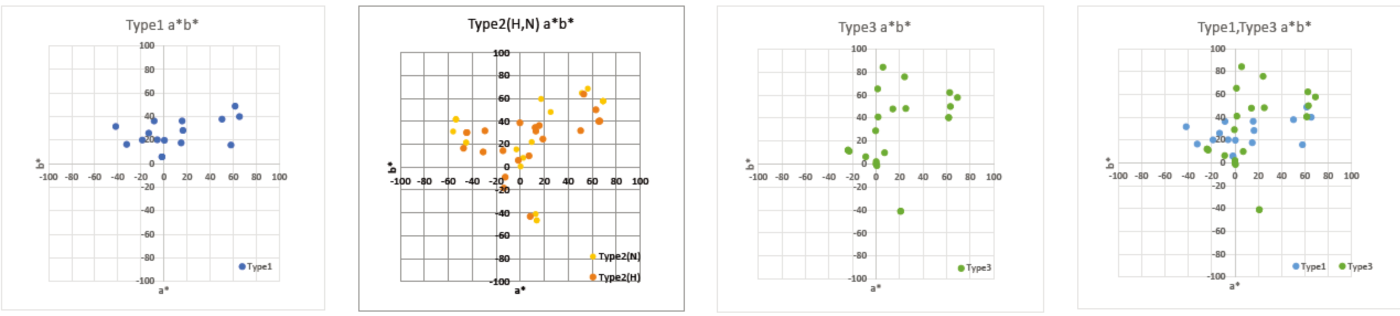


*Fig. 3. Comparative a*b*graphs Type 1, Type 2 and 3 , Type 3, and Type 1 and 3.*

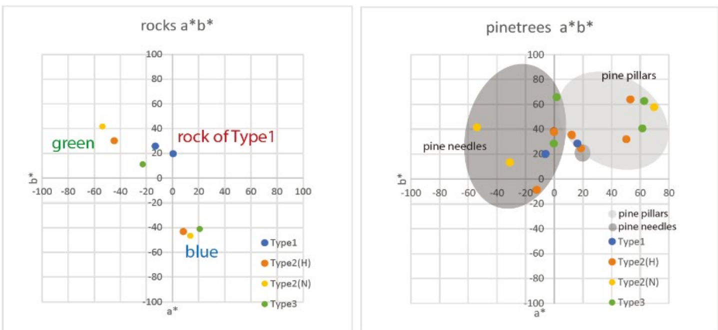


*Fig. 4. a*b*graph of rocks and pines (poles and pine needles) by type.*

4.2. *L*C* Graphs of Sibjangsengdos*

These are the L*C* graphs for each type (See Figure 5). The L*C* graph shows that the overall lightness and saturation increase as you move from Type 1 to Type 2 to Type 3 (See Figure 5**).** You can see that the tone gradually changes (See Figure 6) from dark greyish to vivid (See Table 2).

The L*C* graphs and PCCS tones were analysed. They gradually become brighter and more vibrant as they move through different types.

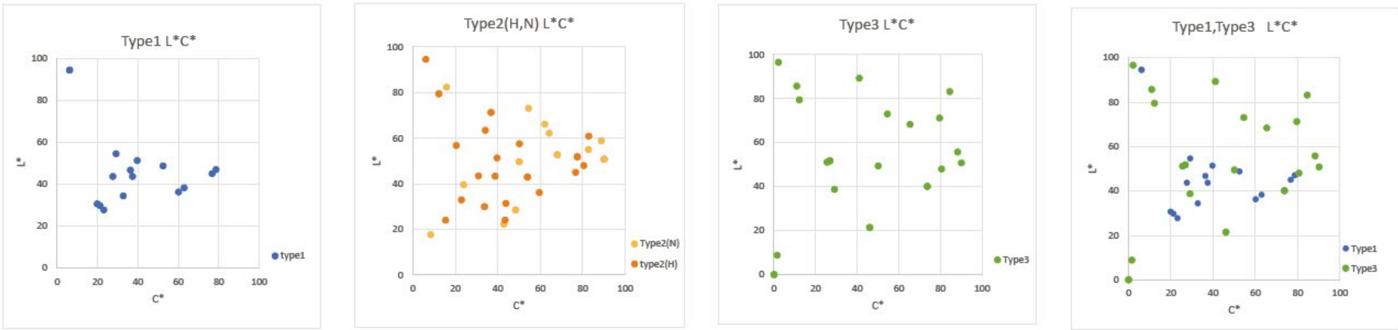


*Fig. 5. Comparative L*C* graphs of Type 1, Types 2 and 3, Type 3, and Types 1 and 3.*

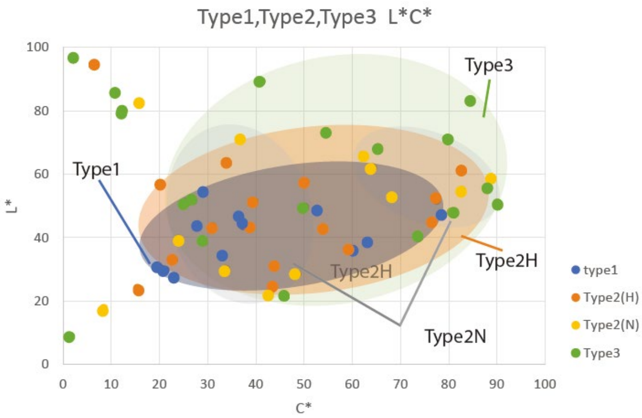


*Fig. 6. Comprehensive L*C* graph of Sibjangsengdo by type.*

5. Discussion

Through the above study, it can be observed that the colours in late Joseon period paintings gradually became more distinct over time. This is due to the gradual increase in colour saturation due to the use of Western pigments introduced in the late Joseon Dynasty. In the case of Type 1, the date is unknown, but the a*b* values of the rocks are L* 54.61, a*-13.24, and b*29.25, which are similar to the category of real stone green (Park, et al., 2015), so it can be assumed that it was painted using traditional pigments. The blue rocks of Type 2 and 3 can be assumed to be imported pigments based on the position of the colour angle by previous research (Lhi, 2024). Green rocks of Type 2 are not part of the traditional range of pigments. However, the green rocks of type 3 have L*51.14, a*-22.89, and b*11.21, which is in the range of malachite. This shows that malachite continued to be used after the pigment change, but the more expensive azurite was replaced by imported pigments. This fact signifies that the development of coloured paintings, which had been suppressed under the Neo-Confucian system, resumed as the system transitioned to Silhak. It also implies that this shift in the system allowed for traditional pigments to be replaced by cheaper organic ones, resulting in a broader and more diverse use of colours. A limitation of this study is that the L*a*b*C* values were obtained as estimates using NCS indices for the analysed objects, so we do not know the exact actual measurements; however, the estimates are within the data range of the actual pigments and are sufficient to look at the colour variation of the late Joseon *Sibjangsengdos*.

6. Conclusion

In the late Joseon Dynasty, the composition of *Sibjangsengdo* changed from Type 1 to Type 2 and Type 3 over time, and the colours also gradually changed from low lightness and saturation to high lightness and saturation, and the tone from greyish to vivid.

7. Conflict of interest declaration

No conflict of interest.

8. Funding source declaration

The authors received no specific funding for this work.

9. Short biography of the author

Wona Lhi- PhD candidate at Ewha Womans University. She specialises in colour design and draws Korean folk paintings. She majored in chemistry at university, so her research focuses on painting and pigments.

***GyoungSil Choi**, has been a Professor at Ewha Womans University since 1995 with researching in color design and interior architecture. Choi received an Engineer Diploma in Interior Architecture from Fachhochschule Duesseldorf, Germany. Choi received her BA in Interior Design from Ewha Womans University, Korea.

Licensing terms

References

Lhi, W., and Park, Y.K. (2024) 'Analysis of Color Changes in Paintings by Era due to Changes in Pigments', Journal of Korea Society of Color Studies, 38(1), pp. 64-72. Available at: 10.17289/jkscs.38.1.202402.64. http:doi.org/10.17289/jkscs.38.1.202402.64

Park, B.S. (2018) 'A Study of the Ten Symbols of Longevity Screen in the Collection of the Museum of Art at the University of Oregon', *Journal of Korean Art and Archaeology (JKAA),* 12, pp. 27-44. https://www.ijkaa.org/assets/pdf/32/jkaa-12-27.pdf

Park, J.H., Jeong, H.Y., Go, I.H., Jeong, S.L. and Jo, A.H. (2015) 'A study on the physical properties of Seokrok and Noerok used as green pigment', *Journal of conservation science,* 31(4), pp. 429-441. DOI http://dx.doi.org/10.12654/JCS.2015.31.4.10

Park, J., Kim, M., Park, S. and Lee, S. (2023) 'Properties and Lightfastness of Natural and Artificial Azurite Used As Painting Pigment', *Korean Journal of Metals and Materials,* 61(9), pp. 704-713. DOI: http://dx.doi.org/10.3365/KJMM.2023.61.9.704

Colorimetry in the conservation of assets integrated into heritage properties: comparative analyzes of hydraulic tiles

Arthur Thiago Thamay Medeiros[1], Fabio Pinto da Silva[2]

[1]*Department of Graphic and Three-Dimensional Expression, Federal University of Bahia, Salvador, Brazil. thiagothamay@ufba.br*

[2]*Department of Design and Graphic Expression, Federal University of Rio Grande do Sul (UFRGS), Porto Alegre, Brazil., fabio.silva@ufrgs.br*

Corresponding author: Arthur Thiago Thamay Medeiros (thiagothamay@ufba.br)

ABSTRACT

With the advent of color measurement technologies in the area of architecture, design and cultural heritage, the use of colorimetry has enabled advances in the conservation of heritage properties, in a non-invasive way. In this sense, the object of study of the research is the Paço dos Açorianos of Porto Alegre - Rio Grande do Sul - Brazil, with thematic delimitation in the hydraulic tiles located in the entrance hall of the ground floor of the building which, currently, present various pathologies. The objective is to use a colorimeter to measure the color of the Paço tiles and compare it with the color sample of the Fábrica de Mosaicos de Pelotas, a company supporting the research and the largest in the segment in the State of Rio Grande do Sul. The methodology used consisted of measuring the samples produced by Fábrica de Mosaicos as a standard and the Paço tiles as a sample and comparing it with, evaluating the differences (deltas) between the measurements to determine if they are within the tolerance established for the color standard, as described by the manufacturer. The results indicated which colors obtained the greatest similarity. The tolerance value used follows the difference formula of CIEDE2000. The work is part of doctoral research that examines the feasibility of using technologies to conserve assets integrated into the building, emphasizing the historical and cultural importance of hydraulic tiles. He proposes a collaboration between science and industry to conserve and enhance these elements, with a view to future restoration works on the pavement.

KEYWORDS colorimetric analysis, cultural heritage, hydraulic tile

RECEIVED 27/03/2024; **REVISED** 05/09/2024; **ACCEPTED** 11/09/2024

---

1. Introduction

Colorimetry, the study of color, is essential in the preservation of cultural heritage. With technological advances for instrumentation in color measurement, colorimeters analyze color with and without contact, using the spectrum generated by reflected light. This is essential in the conservation of assets integrated into listed properties, such as hydraulic tiles, as they do not cause damage to property.

Silva, Nogueira, and Amaral (2020) emphasize that, despite the neglect of color studies in contemporary architecture, the knowledge and treatment of pigments on historical architectural surfaces are essential for the restoration, conservation, and prevention of their degradation. In their research, the authors used a Digital Colorimeter to measure, identify, and map the colors present in the parietal layers of the Solar dos Rollemberg building, in Aracaju, SE, in Brazil. The use of this device enabled a precise characterization of the materials in the mural paintings, ensuring a scientific process of inventory, conservation, and restoration.

Hydraulic tiles, known as mosaics, are manufactured by hand, using methods passed down from generation to generation. Being part of heritage assets, they represent both material and intangible heritage and must be preserved. In addition to their aesthetic value, they contribute to the preservation of memory and local identity in built heritage.

In this sense, the object of study addressed in the research are the hydraulic tiles present on the ground floor of Paço dos Açorianos, an emblematic building located in Porto Alegre – RS, of great historical and cultural relevance. As the former headquarters of the City Hall and the Pinacoteca Aldo Locatelli, this space carries with it the administrative memory of the city and the architectural expression of its time.

The objective of the research is to use a colorimeter to analyze the color of the tiles present on the floor of Paço dos Açorianos, followed by comparing these results with the color sample made available by the renowned Fábrica de Mosaicos de Pelotas. This company, which offers research support, stands out as the largest representative of the sector in the State of Rio Grande do Sul, being recognized as a Brazilian industrial heritage due to its position as the oldest tile factory in continuous operation in Brazil.

The collaboration of Fábrica de Mosaicos de Pelotas not only enriches the research with its vast experience and knowledge in the field of hydraulic tiles, but also demonstrates a joint commitment to the preservation of the State's cultural heritage.

The methodology adopted involved measuring the samples produced by the Mosaics Factory as a standard, and the Paço tiles as a sample, using a colorimeter. The measurements were compared, evaluating the differences (deltas) to verify whether they are within the tolerance established by the manufacturer for the color standard. The tolerance value used follows the difference formula of CIEDE2000 (CIE, 2001), based on data provided by Sharma, Wu and Dalal (2005).

In the present research, a similar colorimeter was used to differentiate the acquired data, based on a color calculation methodology of the spectrophotometric method.

Based on these criteria, a comparison was made between the previously measured standard (factory sample) and the sample (Paço tiles), following the colorimeter manufacturer's instructions.

This data is represented in CIELAB space, where "L" is luminance and "a" and "b" are chromatic axes. The "a" axis represents the green/magenta spectrum, while the "b" axis indicates the blue/yellow spectrum. The location of the color in this space makes it possible to compare colors, with the difference measured as ΔE.

Through comparative analysis of the pattern and samples, it was defined that the colors of the Paço dos Açorianos tiles that were most similar to the Factory's display were: 05 Orange, 09 Chocolate, 10 Dark Grey, 14 Dark Blue, 18 Bronze, 21 Off-White and 22 Caramel.

Challenges during data collection, such as lightness, can affect color perception and cause errors. Geometric metamerism can also lead to color mismatches. Measuring and evaluating the colors of the Paço tiles is challenging due to yellowing, dirt and excessive shine from the waxes applied over the years. To achieve greater color accuracy, it would be necessary to sand the damaged surface, which is not feasible due to the heritage status. Therefore, colorimetric measurements, using a colorimeter, are themselves non-invasive.

The work is part of doctoral research whose main focus is to investigate the feasibility of means for conserving assets integrated into the building (MEDEIROS, 2023). The research carried out in partnership between a public university and the Ball Mosaic Factory generated important benefits for the conservation of a heritage relevant to Porto Alegre and the Rio Grande do Sul. This collaboration between science and industry resulted in an applied research, promoting a dynamic interaction between institutions. The cooperation allowed the Factory to sustainably and replicate the research results, pointing out new paths for future restoration and conservation projects.

This research was funded by the Coordination of Superior Level Staff Improvement (Capes) together with the Postgraduate Program in Design (PGDesign) at the Federal University of Rio Grande do Sul (UFRGS), in partnership with the Fábrica de Mosaicos de Pelotas and carried out with the support of the Cultural Memory Coordination of the Porto Alegre - RS Department of Culture and the Design and Material Selection Laboratory (LDSM) of UFRGS.

1. 2. *Color measuring instruments: colorimeter*

In order to improve understanding of the procedures used to measure color with equipment, it is essential to investigate the crucial role of the colorimeter in this context.

The International Commission on Illumination - CIE (Commission Internationale de l'Éclairage - international organization whose work is based on the use of light and color) conducted studies to determine the intensity of each color present in the visible spectrum, using three primary colors: green, blue and red. Through these studies, it was possible to map all colors and represent them graphically in three curves (XYZ). This advance allowed the development of color measurement devices, capable of capturing and calculating the corresponding tristimulus values (DELTA COLOR, 2023).

The colorimeter is a device composed of an internal light source and three sensors that filter blue, green and red colors. Using mathematical matrices, this system is capable of measuring the amount of light reflected by the sample and converting the data to the XYZ color space, thus seeking a representation similar to human visual perception (DELTA COLOR, 2023). It is important to note that this assumption is true only for tristimulus colorimeters.

The L*, a*, and b* coordinates in CIELAB are utilized to determine the position of any color within the uniform color space defined by this system. However, in most industrial contexts, it is employed to assess how much an object's color deviates from the standard, both in colorimetric terms and in visual match acceptability. For this purpose, similar to the Hunter Lab system, it is possible to quantify differences for each L*, a*, and b* coordinate, and also to calculate total color differences using the following formula (MACDOUGALL, 2002):

$$\Delta E^* = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{½}$$

ΔE enables the measurement of variations in hue and density. The average observer typically notices differences of 5 or 6 ΔE or more. Only a highly trained eye can detect differences of 3 to 4 ΔE. The human eye is significantly more sensitive to changes in gray levels and midtones, and in such cases, it can perceive differences as small as 0.5 ΔE (MACDOUGALL, 2002).

For color quality control applications widely adopted in industry, the use of a colorimeter may be appropriate and provide satisfactory results, for example, in hydraulic tile factories that require control over the color pattern used. This instrument is capable of measuring a color standard and comparing it with the samples produced, evaluating the differences (deltas) between measurements to determine whether they are within the tolerance established for the color standard.

2. Hydraulic tile

Hydraulic tile is a coating composed of cement, aggregates and pigments, used on floors and walls. NBR 9457 (ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS, 2013, p. 1) defines it as a double-layer parallelepiped cement slab, produced by pressing, with the surface exposed to traffic smooth or in low relief.

The primary raw material is Portland cement, as specified by the standard, which also stipulates the composition of the mortar, allowing the use of additives and pigments. Water plays a crucial role in hydrating the cement during the curing process, in order to avoid cracks and cracks in the tiles.

Despite being mechanized in series, hydraulic tiles are considered manufactured products, as each piece is individually made by the artisan, giving them uniqueness.

Historically, its popularity grew during the Modern period, influenced by Art Nouveau and Art Deco, with several specialized designers and prominent artists responsible for creating the patterns. The predominant colors are brown, green, pink, yellow, cream, gray, white and black, although others are also used (NAVARRO, 2006).

However, the advancement of demolitions of historic buildings threatens the preservation of the history of hydraulic tiles, whose centuries-old manufacturing process remains, although some raw materials have evolved or become extinct.

In recent years, architecture, engineering and design professionals have valued these coverings as an integral part of cultural heritage, recognizing their importance in both material and immaterial dimensions. It is essential to understand the definitions of heritage to determine which category the hydraulic tile is classified in.

2.1. *Integrated assets and cultural heritage*

With the expansion of concepts and categories within the scope of cultural heritage, the need to recognize and protect assets that do not strictly fall within the definition of architecture has arisen. In recent decades, Iphan has implemented measures to safeguard integrated cultural assets, recognizing their importance as historical, artistic and cultural documents, as well as the symbolic and affective relationships they maintain with architectural elements.

In 1986, the National Inventory of Movable and Integrated Assets (INBMI) was established, aiming to systematically identify and catalog listed movable and integrated assets, with a special focus on religious buildings. These assets, which include decorative and constructive elements of buildings, such as paintings and tile panels, remain attached to the built surface and can only be removed with careful effort, leaving a visible mark of their origin (IPHAN, 2023).

According to Costa (1987), integrated assets encompass those that are directly linked to the built structure, both internally and externally, and that can only be successfully removed through careful and planned effort. However, even when removed, these elements still leave a visible mark of the intervention carried out in their place of origin. This category covers all items fixed in architecture and that are an integral part of the monument, including the internal decoration of residences, fortresses, palaces, museums, churches and convents. All decorative and constructive elements present in these buildings, such as paintings and tile panels, are part of this category of integrated goods.

According to Dominguez (2016), there is the possibility of integrating hydraulic tiles into this categorization and including them in standards, programs and preservation instruments already established by the Brazilian state. This would allow them to be aligned with public policies aimed at disseminating information and preserving heritage, through existing legal instruments for this purpose.

In short, the integration of hydraulic tiles into historical heritage preservation policies can significantly contribute to its safeguarding and appreciation. By recognizing their importance as integrated elements, it is possible to establish specific guidelines and measures for their conservation, aligned with the principles established by existing legal instruments. This not only protects these cultural elements for future generations, but also promotes awareness of their historical and cultural relevance, enriching society's collective identity and memory.

3. Materials and methods

To carry out a comparative analysis of the colors of the hydraulic tiles at Paço dos Açorianos with the sample at Fabrica de Mosaicos de Pelotas, aiming to select the colors for the manufacturing stage, color data were acquired with a colorimeter by Delta Color (São Leopoldo/RS - Brasil) model Colorium. The Colorium colorimeter works in conjunction with the Lab7 Software (DELTA COLOR, 2023).

To validate the procedure adopted, the colorimeter manufacturer suggests that the sample be measured and stored as a “standard”. Then perform the measurement again as a “sample”. Ideally, the color difference (ΔE) between these measurements should be a maximum of 20% of the value adopted for the tolerance. If the variation between measurements of the same sample is greater than this percentage over the tolerance, then it is likely that the procedure will not be accurate or consistent (DELTA COLOR, 2023).

4. Results

To carry out a comparative analysis between the color of the Paço dos Açorianos (Fig. 1) tiles and the shades present in the Fábrica de Mosaicos color catalog (Fig. 2), the colorimeter measured a pre-determined standard (the Fábrica de Mosaicos color sampler), together with the sample in question (a tile from the Paço dos Açorianos), thus allowing the measurement variation (delta) between both to be assessed. In this way, it was possible to check whether the color of the sample was within the pre-established tolerance of 1.5.

Fig. 1. Use of the colorimeter on the tiles from Paço and the sample from the Fábrica de Mosaicos.

Fig. 2. Use of the colorimeter on the tiles from Paço dos Açorianos.

Tolerance values should be defined internally or between the supplier and the consumer and used in quality control to determine whether the sample passes the inspection process (CARBALLO-REYES et al., 2023).

According to Jara (2023), tolerance values should be defined internally or between the supplier and the consumer and used in quality control to determine whether the sample passes the inspection process. Considering that a value greater than 2 is highly noticeable, and for it to be imperceptible to the human eye, it must be less than or equal to 0.5 (FERNÁNDEZ-QUESADA; ALONSO-MUÑOZ, 2024).

The analyses conducted with the Colorium Colorimeter, using the Lab7 Software, revealed that, despite the exact chromatic match between the hydraulic tiles from Paço dos Açorianos and the sample from the Fábrica de Mosaicos, the surfaces exhibit distinct textural characteristics. While the original tiles have a slightly irregular texture, with subtle signs of aging and natural wear over time, the newly produced tiles feature a more uniform and smooth surface, a result of contemporary manufacturing processes. Therefore, although the colors are identical, the difference in texture is a factor to consider, as it directly impacts the visual and tactile perception of the material.

When performing measurements, the colorimeter provided measurement Deltas in the CIE L*a*b* color system. The CIE has developed methods to represent colors numerically and one of these methods is the Lab chromatic measurement system (Fig. 3).

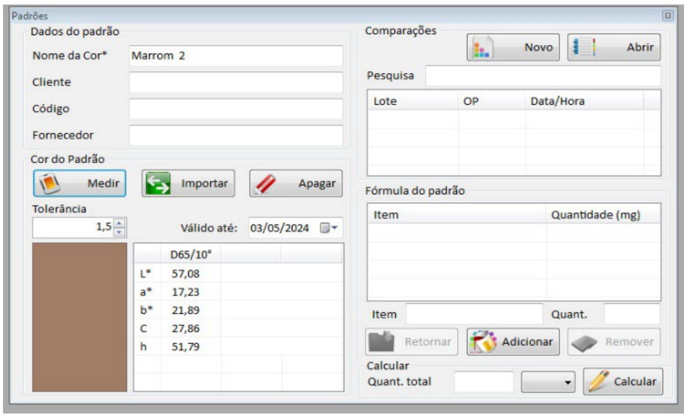


Fig. 3. Pattern data measured with the colorimeter.

Adobe Photoshop graphic editing software offers advanced automated functionalities for color conversion between different chromatic systems. Among these, the conversion from the Lab color system to the RGB system (light-based, composed of Red, Green, and Blue) and the CMYK system (pigment-based, consisting of Cyan, Magenta, Yellow, and Black) stands out. These features facilitate the transposition of chromatic information between color models used in different technologies (Fig. 4).

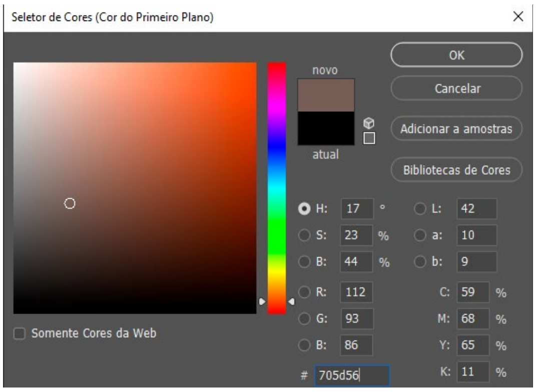


Fig. 4. Color system conversion using Adobe Photoshop.

The conversion of colors between systems proved to be crucial for obtaining the respective color codes in each model. This step is essential to ensure the correct visualization of colors both on electronic devices, which use the RGB system, and in printed media, which operate with the CMYK system. The conversion helps maintain chromatic integrity across different platforms, ensuring consistency and accuracy in the results presented in both digital and physical formats (Table 1).

The same procedure was applied to the color catalog of Fábrica de Mosaicos. The 30 available colors in the catalog were carefully measured and subsequently converted to the RGB and CMYK systems. After the measurement stage, a comparative analysis between the color standards and the samples was conducted using the Lab7 software, developed for the colorimeter, to ensure the accuracy and consistency of the obtained results (Table 2).

To understand the results obtained with the comparative analysis, it is important to understand the acronyms L*a*b* C* h*and their meanings – L* main axis (black = 0 to white = 100); a* (green [-] to red [+]) and b* (blue [-] to yellow [+]. C* represents the saturation and h* the hue. The higher the L* values mean lighter colors, consequently , smaller values indicate darker colors. L* values range from 0 to 100 and a* and b* values range from -128 to 127 (Fig. 5).

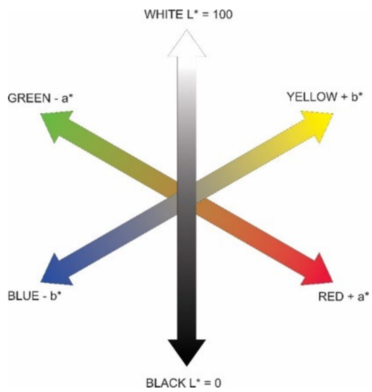


Fig. 5. CIE L a* b* color space.*

COLOR NAME	HUE	COLOR SYSTEMS									
		Lab			RGB			CMYK			
Orange		66	40	35	212	128	101	7	66	61	0
Chocolate		57	17	21	160	124	102	39	58	63	0
Dark grey		68	3	16	174	162	137	36	35	49	0
Dark blue		50	-7	-9	114	119	132	66	53	42	0
Bronze		70	15	37	198	159	107	22	43	66	0
Dirty White		99	-3	5	250	254	242	5	0	9	0
Caramel		90	0	50	243	224	133	7	15	60	0

Table 1. Colors measured with the Paço tile colorimeter and its color systems.

COLOR NAME	HUE	COLOR SYSTEMS									
		Lab			**RGB**			**CMYK**			
01 White		99	-5	3	247	255	246	7	0	8	0
02 Cream		99	-3	2	249	254	248	5	0	5	0
03 Gray		94	-3	4	236	239	229	11	5	14	0
04 Yellow		89	-3	67	239	222	98	11	13	77	0
05 Orange		65	35	28	202	131	110	14	63	56	0
06 Salmon		60	37	26	192	119	104	18	68	58	0
07 Light Red		58	44	25	190	104	98	18	76	58	0
08 Dark Red		56	27	15	166	115	109	34	66	54	0
09 Chocolate		59	13	15	160	132	116	42	52	55	0
10 Dark Gray		64	3	7	160	152	142	42	38	43	0
11 Medium Green		70	-4	19	172	171	138	39	28	51	0
12 Aqua Green		94	-21	14	216	249	210	27	0	29	0
13 Dark Green		59	-5	6	137	143	131	55	38	51	0
14 Dark Blue		64	-7	-22	133	159	191	61	31	18	0
15 Light Blue		62	2	-58	107	151	250	72	43	0	0
16 Pink		79	27	16	232	175	166	0	43	29	0
17 Terracotta		60	25	26	178	126	101	29	61	63	0
18 Bronze		76	3	30	200	183	133	25	28	56	0
19 Black		20	-2	0	50	53	52	83	77	70	44
20 Grape		63	19	3	174	139	146	33	51	34	0
21 Dirty White		99	-5	10	250	255	233	6	0	14	0
22 Caramel		86	3	55	235	210	114	10	21	69	0
23 Greenish Yellow		99	-10	34	253	255	187	8	0	37	0
24 Pastel Blue		95	-18	-5	215	252	250	27	0	10	0
25 Cobalt Blue		73	-49	-43	51	204	255	87	0	12	0
26 Strong Light Green		80	-27	17	170	211	166	48	0	48	0
27 Lead		69	-1	0	166	167	167	41	30	31	0
28 Hot Pink		73	50	21	240	138	142	0	64	32	0
29 Pastel Pink		96	5	-2	248	238	245	0	11	0	0
30 Blue-Green		66	-8	-3	148	163	164	52	28	34	0

Table 2. Colors measured with the colorimeter in the Fábrica de Mosaicos showcase and its color systems

Once you have the color difference values, it is possible to establish acceptance limit values, the so-called colorimetric tolerance. This tolerance varies for each industry, depending on the acceptance of the customer it serves (DELTA COLOR, 2023).

In this study, the CIEDE2000 method was used to calculate the color difference between the analyzed samples. CIEDE2000 is an advanced method that evaluates color differences based on human visual perception, taking into account luminance, chromaticity, and other relevant factors (SHARMA, WU AND DALAL, 2005).

The LAB color coordinates of the samples were obtained and used to calculate the initial differences (ΔL, Δa, Δb). Subsequently, the means of these coordinates were calculated and chromatic corrections were made to adjust the a and b components, considering the luminance weighting (SL), chromaticity (SC), and the rotation factor (RT). The full CIEDE2000 formula was then applied to determine the final perceptual color difference, ΔE00. These precise calculations were carried out using the Lab7 software developed by the colorimeter manufacturer.

For the present analysis, a tolerance of 1.5 was established. As the manufacturer indicates that the tolerance should not exceed 20%, the maximum tolerance value can reach 1.8. Based on the stipulated value, the standard (Fabrica de Mosaicos sample) previously measured was compared with the sample (Paço dos Açorianos tiles), as recommended by the colorimeter manufacturer. The colors of the Paço dos Açorianos tiles that were most similar to the display were: 05 Orange, 09 Chocolate, 10 Dark Grey, 14 Dark Blue, 18 Bronze, 21 Dirty White and 22 Caramel.

When comparing color 05 Orange, the tolerance scale was 2.5, 1 point above the established percentage. Reading the data, it was found that the sample had a lighter L* value and a redder a* value. b* has the same tone. C* had a more vivid color, that is, more saturated (Fig. 6).

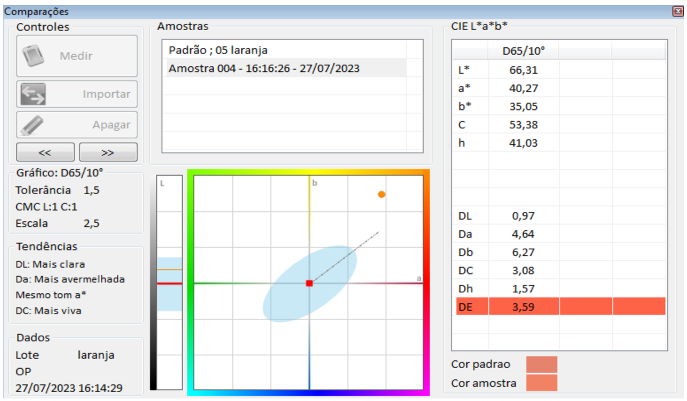


Fig. 6. Laranja color comparison chart.

When comparing the color 09 Chocolate, the value obtained exceeded the tolerance scale, scoring 5.25. However, given the colors on the factory display, this is the one that most closely resembles the color of the tiles at Paço dos Açorianos, which is why it was selected. Reading the data, it was found that the sample had a lighter L* value compared to the standard and a redder a*. B* introduced himself with the same tone. The C* that represents saturation showed that the sample had the most vivid color (Fig. 7).

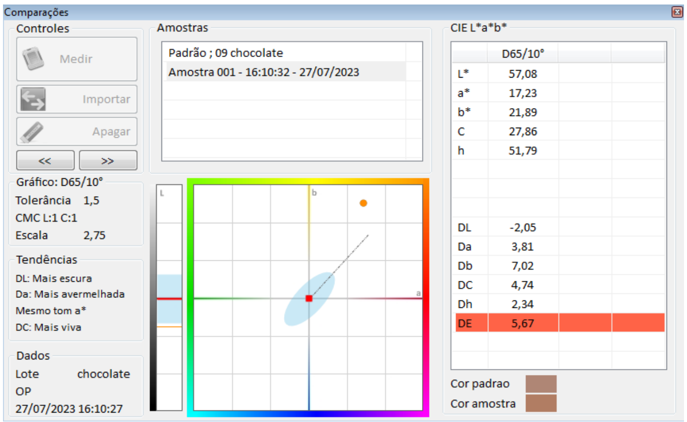


Fig. 7. Chocolate color comparison chart.

When comparing the color 10 Dark Gray, the tolerance scale was 3.5, 2 points above the established percentage. Reading the data, it was found that the sample had the L* value lighter, a* more reddish, b* the same tone and C* more vivid (Fig. 8).

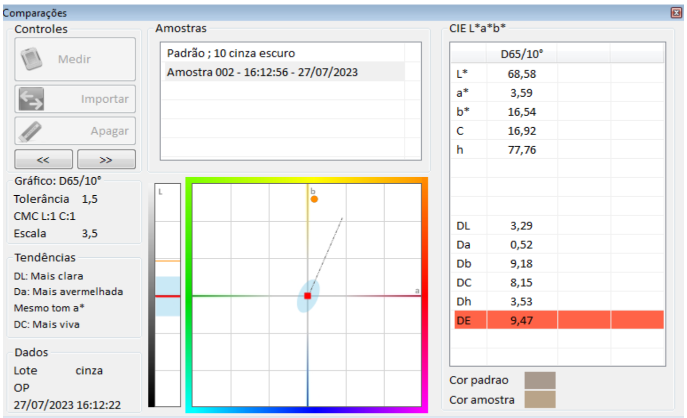


Fig. 8. Cinza Escuro color comparison chart.

When comparing the color 14 Dark Blue, the tolerance scale was 9. Among the colors selected, this was the shade in which the value obtained exceeded the tolerance scale too much, however, compared to the colors on the Fábeica de

Mosaicos display, it is the one that most It resembles the color of the tiles at Paço dos Açorianos, which is why it was selected. Reading the data, it was found that the sample had the L* value lighter, a* more reddish, b* with the same tone as a* and C* more opaque (Fig. 9).

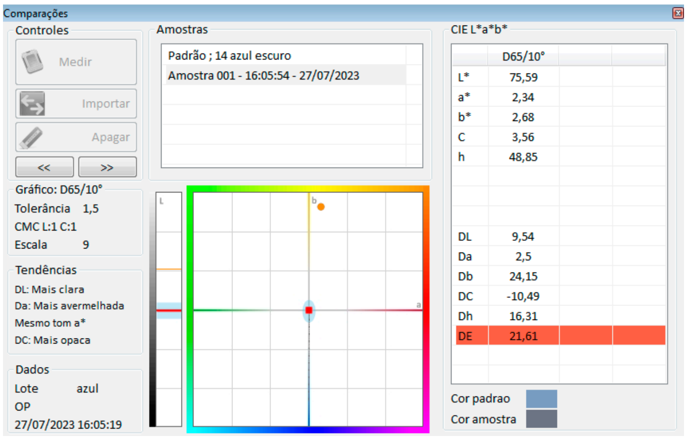


Fig. 9. Azul Escuro color comparison chart.

When comparing color 18 Bronze, the tolerance margin was 4.5, exceeding the stipulated percentage by 3 points. When analyzing the data, it was found that the sample exhibited a darker L* value, a more intensely reddish a* tone, a b* with the same tone as a*, and a more vibrant C*, as demonstrated in image (Fig. 9). This set of observations highlights the specific nuances of color and its variations in relation to established standards.

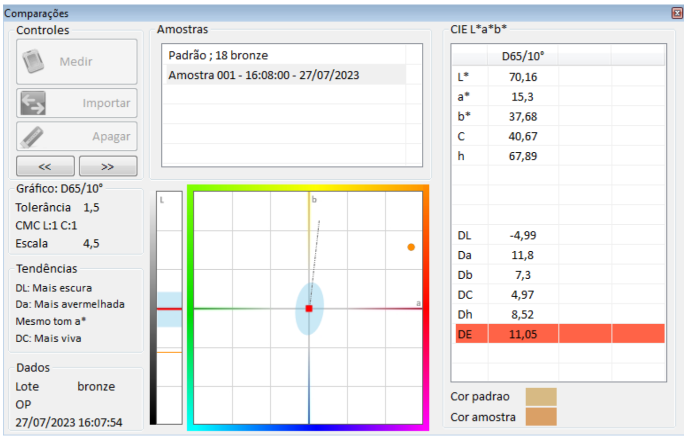


Fig. 10. Bronze color comparison chart.

When comparing the color 21 Dirty White, the tolerance was 1, within the acceptable percentage. This was the only highly compatible shade. The luminosity (L*) and red tone (a*) values were the same, with a more yellowish tone (b*), and the same chroma (C*). (Fig. 11).

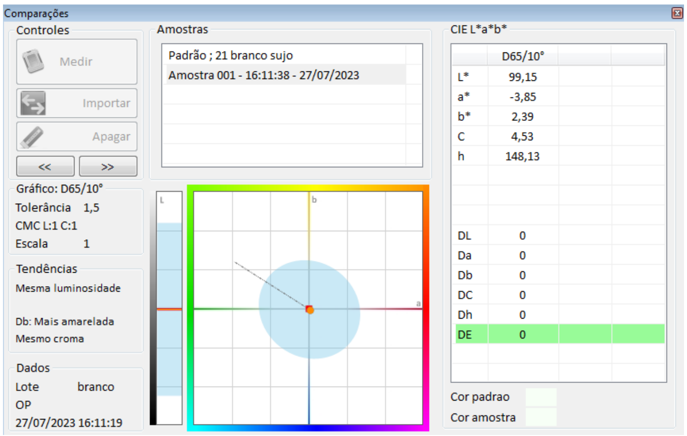


Fig. 11. Branco Sujo color comparison chart.

Finally, when comparing the color 22 Caramel, the tolerance scale was 3, being 1.5 above the established percentage. Reading the data, it was found that the sample presented a lighter L* value, a* more greenish, b* the same tone as a* and C* more vivid (Fig. 12).

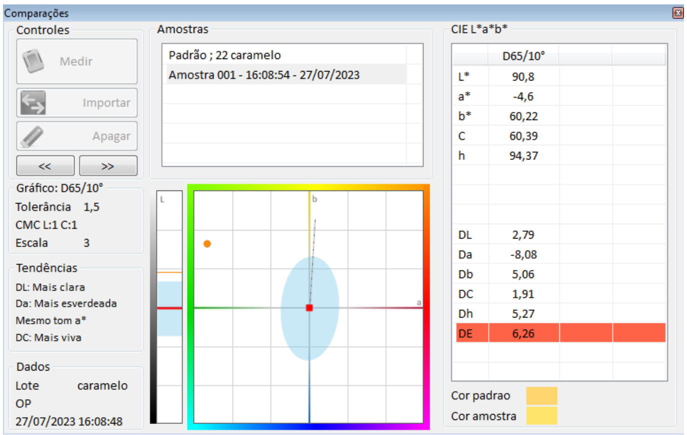


Fig. 12. Caramelo color comparison chart.

5. Discussion

According to the standard ASTM (2017), brightness can influence color perception and result in very costly errors. Likewise, the effects of geometric metamerism, if not taken into account in assessment observations, will result in color mismatches.

Therefore, it is understood that measuring and evaluating the colors of the city hall's tiles proved to be a complex task, since the damage caused by yellowing, dirt and excess shine from the waxes applied over the years to polish the surface, can cause imprecision in the color, which can make hues more saturated and less luminous (Fig. 13).

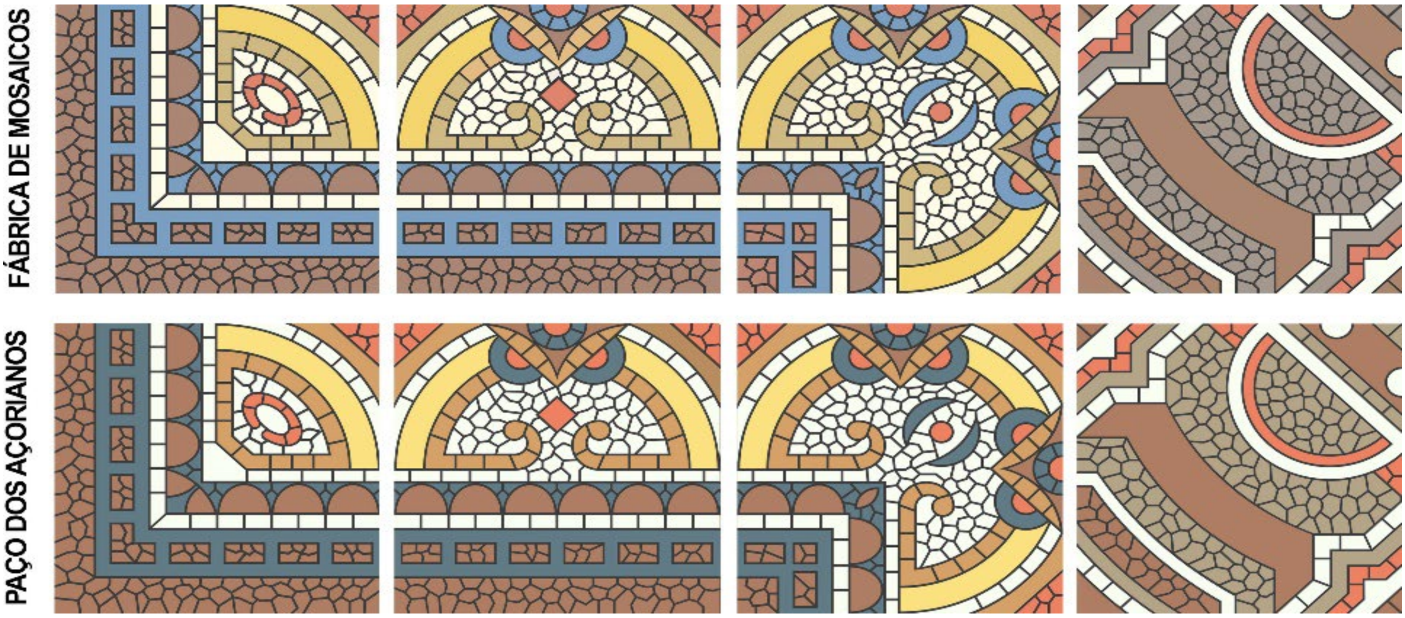


Fig. 13. Demonstrative illustration with the colors applied to the tiles made by Fábrica de Mosaicos and those at Paço dos Açorianos.

To obtain the exact color, it would be necessary to carry out a sanding process to reach a deeper, damage-free layer. Therefore, it would be possible to carry out a study with the preparation of various test bodies based on mixtures of pigments from the Fábrica de Mosaicos, to then achieve the most compatible tone, however, as we are dealing with an asset integrated into a listed heritage property, such action is not viable the decision to use a colorimeter reinforces the choice to use indirect data capture methods that do not cause further damage to property.

6. Conclusion

Conceptually interdisciplinary research, combining design, architecture, new technologies and cultural heritage, provides, through its results, the potential to promote the conservation of hydraulic tiles, contributing to the advancement of scientific knowledge in these areas. By combining academic research in partnership with Fábrica de Mosaicos de Pelotas, innovative strategies for manufacturing were developed.

In this context, the use of a colorimeter proved to be a viable and effective alternative, allowing accurate measurement of colors without compromising the physical integrity of the tiles. This choice reflects the commitment to preserving cultural and historical heritage, while at the same time enabling advances significant in the understanding and conservation of hydraulic tiles.

The research reaffirms the cultural and heritage importance of hydraulic tiles, highlighting the collaboration between science and industry in the preservation and valorization of this element in the Paço dos Açorianos. This partnership paves the way for future restoration interventions on the pavement, ensuring its conservation for future generations. Furthermore, cooperation between the institutions involved allowed the sustainable and replicable incorporation of research results by Fábrica de Mosaicos, suggesting new directions for future restoration and conservation projects. By combining scientific methods with the practical expertise of the Fábrica de Mosaicos de Pelotas, the aim was to contribute to a better understanding and conservation of this integrated asset. In summary, the research results have the potential to assist other researchers and professionals involved in the conservation of tiled floors, highlighting the crucial role of the colorimeter in the manufacturing process of these coverings. By demonstrating the effectiveness of this tool in accurately measuring colors, this study contributes to the development of more efficient practices in colorimetry.

Regarding the developments of this research, it is suggested to investigate the development of specific shades of pigments for hydraulic tiles intended for heritage properties. This would involve researching and testing pigment formulations that meet the aesthetic and preservation requirements required for such historic spaces

7. Conflict of interest declaration

The authors declare no conflict of interest.

8. Funding source declaration

This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – Brasil (CAPES) - Finance Code 001.

8. Short biography of the author(s)

Arthur Thiago Thamay Medeiros - PhD in Design, with a concentration in Design & Technology from the Federal University of Rio Grande do Sul (UFRGS), Master's degree in Design, and a Bachelor's degree in Product Design from the Federal University of Campina Grande (UFCG). He is currently an adjunct professor in the Department of Graphic and Three-Dimensional Expression at the School of Fine Arts at the Federal University of Bahia (UFBA). He is an expert member of CIPA Heritage Documentation, the International Council on Monuments and Sites (ICOMOS - Brazil), and the Brazilian Committee for the Conservation of Industrial Heritage (TICCIH - Brazil).

Fabio Pinto da Silva - Graduated in Mechanical Engineering from UFRGS (2002), Master's (2006) and Doctorate (2011) in Engineering, with an emphasis on Materials Science and Technology, from PPGE3M/UFRGS. He is currently an Associate Professor in the Department of Design and Graphic Expression (DEG/FA/UFRGS) and works as a consultant for the main national and regional funding bodies, such as CNPq, CAPES and FAPERGS. Since 2017, he has been leader of the LDSM/UFRGS (DGP/CNPq) research group. Since 05/2021 he has been coordinator of PGDESIGN/UFRGS.

Licensing terms

References

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. (2013). NBR 9457: Hydraulic tiles for paving - Specification and test methods. Rio de Janeiro.

ASTM. (2017). D1729-16: Practice for Visual Appraisal of Colors and Color Differences of Diffusely-Illuminated Opaque Materials, Available at: http://dx.doi.org/10.1520/d1729-96 (Accessed: 17 May 2023).

CARBALLO-REYES, Laura et al. (2023). Análisis colorimétricos de galletas utilizando el Sistema Internacional CIELAB. Revista Multidisciplinaria de Ciencia, Innovación y Desarrollo - REMCID, v. 31, n. 27, p. 27-31. (Accessed: 17 jul. 2023).

CIE (2001). Improvement to industrial colour-difference evaluation. Vienna: CIE Publication No. 142-2001, Central Bureau of the CIE.

COSTA, L. M. (1987). The defense of movable cultural heritage. National Historical and Artistic Heritage Magazine, nº 22, 1987, P. 145-157. Available at: https://encurtador.com.br/vFOT1 (Accessed: 29 May 2023).

DELTA COLOR, Brazil. (2023). Articles. Available at: https://www.deltacolorbrasil.com/artigos.html. (Accessed: 06 August 2023).

DOMINGUEZ, A. J. A. (2016). Hydraulic tiles: assets integrated into listed buildings in Pelotas-RS. 254f. Dissertation (Master's in Social Memory and Cultural Heritage) – Postgraduate Program in Social Memory and Cultural Heritage, Institute of Human Sciences, Federal University of Pelotas, Pelotas.

FERNÁNDEZ-QUESADA, Blanca; ALONSO-MUÑOZ, Fernando. (2024). Cazar Colores. La relatividad cromática en las APPs de color como caso de estudio Colors Hunt = Chromatic relativity in color APPs as a case study. Ardin. Arte, Diseño e Ingeniería, [S.L.], n. 13, p. 1-25, 1 abr. 2024. Universidad Politecnica de Madrid - University Library. http://dx.doi.org/10.20868/ardin.2024.13.5212.

JARA, Leidy Jamileth Ruiz. (2023). Physicochemical Parameters for the Production of Ñuña (Phaseolus vulgaris L.) Snacks, Subjected to Different Times and Types of Oil. 2023. 73 f. Doctoral Thesis - Engineering in Food Industries, National University of Cajamarca, Peru.

IPHAN. (2023). Movable and Integrated Goods. Available at: http://portal.iphan.gov.br/pagina/detalhes/1299. (Accessed: 06 August 2023).

MacDougall, D. (2002). Colour in food: Improving quality. CRC Press, EE.UU; Woodhead Publishing Limited, Inglaterra, pp. 35-46.

MEDEIROS, A. T. T. (2023). The use of 3D technologies in heritage properties: conservation of hydraulic tiles in the entrance hall of Paço dos Açorianos in Porto Alegre. 280 p. Thesis (Doctorate in Design) – Engineering School / Faculty of Architecture, Federal University of Rio Grande do Sul, Porto Alegre.

NAVARRO, M. A. H. (2006). Barcelona tile designs. Amsterdam: The Pepin Press.

SILVA, Eder Donizeti da; NOGUEIRA, Adriana Dantas; AMARAL, Allyne Almeida. (2020). Identification and Mapping of Colors on Architectural Surfaces: The Case of Solar dos Rollemberg in Aracaju/SE. Brazilian Journal of Development, [S.L.], v. 6, n. 8. Brazilian Journal of Development. http://dx.doi.org/10.34117/bjdv6n8-271.

SHARMA, Gaurav; WU, Wencheng; DALAL, Edul N. (2005). The CIEDE2000 Color-Difference Formula: implementation notes, supplementary test data, and mathematical observations. Color Research And Application, [s. l], v. 30, n. 1, p. 21-30.

Paintings: monitoring varnish variations and their effect on color perception. A case study.

Claudia Gisela Reichold[1], Irene Pieralli[2], Elisa Gualini[3], Serena Hirsch[4], Serena Morrocchesi[3], Marcello Picollo[2]

[1] *Italian Ministry of Culture - qualified restorer, owner of Pinxit, Florence, Italy; restauro.dipinti.firenze@gmail.com*

[2] *Institute of Applied Physics 'Nello Carrara' of the National Research Council (IFAC-CNR), Via Madonna del piano 10, 50019 Sesto Fiorentino (Florence), Italy; m.picollo@ifac.cnr.it, irenepieralli19@gmail.com*

[3] *Department of Chemistry, University of Florence, Via della Lastruccia 3, 50019 Sesto Fiorentino (Florence), Italy; elisa.gualini@unifi.it, serena.morrocchesi@unifi.it*

[4] *Centro per la Conservazione ed il Restauro dei Beni Culturali "La Venaria Reale", Via XX Settembre 18, 10078 Venaria Reale (Turin), Italy; serena.hirsch@ccrvenaria.it*

Corresponding author: Irene Pieralli (irenepieralli19@gmail.com)

ABSTRACT

Color monitoring is one of the methods used for following degradation on varnish applied on paintings. Collecting colorimetric data for monitoring purposes is done effectively, rapidly, inexpensively and non-invasively. In general, colorimetric data are easy to record and read, but the variables associated with them are not always given due consideration. Starting from a specific case study, the panel painting 'Resurrection of Christ and Saints' (1568) by Giorgio Vasari in the basilica of Santa Maria Novella in Florence (Italy), an attempt was made to define a working methodology while providing suggestions for proper planning for monitoring and evaluating the acquired data. The colorimetric data were acquired using a Konica-Minolta model CM-700d colorimeter. The methodology accuracy and repeatability was assured by evaluating the repositioning operations of the instrument on the area of measurements over time, also keeping in mind possible errors induced by operators.

KEYWORDS: varnish for paintings, colorimetric measurements, spectrocolorimeter, Giorgio Vasari, Santa Maria Novella.

RECEIVED 24/05/2024; **REVISED** 02/08/2024; **ACCEPTED** 10/09/2024

1. Introduction

A painting is created by layers of color (pigment and binder) often protected by an outer layer of varnish. The eye perceives the image itself as formed by the varnish-paint system. Consequently, any variation in the varnish inevitably has an effect on this system, causing the color of the image to be perceived differently. The main function of varnish is fundamentally aesthetic as its presence improves the optical characteristics of the painted surface, making it glossier (decreasing the component of diffuse light), smoother and more uniform, and increasing the saturation of colors (Bestetti, 2020; Chercoles et al., 2011; de la Rie, 1992; Maines and de la Rie, 2005; Phenix, 1993). The final varnish of a polychrome work, being the outermost layer, is the one that, due to its position and nature, is exposed to the greatest degradation by external agents. The materials originally used for varnish, traditionally natural resins, change mainly due to photo-oxidative degradation caused by exposure to ultraviolet (UV) radiation and oxygen, resulting in yellowing, loss of transparency, cracking and loss of solubility (Bestetti, 2020; Stoner and Rushfield, 2012).

Non-invasive imaging and analytical techniques are of great importance in the field of preventive conservation of cultural heritage (Aldrovandi and Picollo, 2007; Pinna et al., 2009) as they can be applied on artworks by replicating measurements over time. Among the various methodologies that fall into this group, the use of devices for defining the color of surfaces, or parts of them, is very useful for monitoring the color of artworks over time to highlight any color changes. Colorimetry, in fact, is widely used in the field of art conservation. This technique is commonly used to monitor color over time and highlight color changes that may occur, for example, as a result of alteration processes or to highlight metamerism phenomena following exposure of the artwork to light with different emission spectra. It is particularly useful for monitoring cleaning and inpainting procedures on polychrome works; for measuring color before, during and after such operations (Bacci et al., 2003; Johnston-Feller, 2001; Vila and Murray, 2022).

Colorimetric measurement at several points of the artwork can be a useful indicator of the stability of the varnish-paint system and thus of the varnish itself.

Measuring the color of selected areas of a work of art is a simple operation, but there are many variables that, if not considered or approached superficially, can invalidate a planned monitoring over years. The most important of these are the following:

1. The selection of the areas for analysis over the years. This operation must take into account a series of considerations including: a) accessibility of the artwork throughout the investigation period; b) color homogeneity of the paint layer in the area of interest; c) choice of colors particularly sensitive to variations due to the aging of the external film-forming layer; d) implementation of a method for the correct positioning of the instrumentation on the measurement areas; e) in the case of using positioning systems with reference masks, check the ease of placement before starting the measurement campaign.
2. If measuring masks are used, this operation requires a transparent material: a) stable over time, i.e. one that does not deform over the years (ideally is a sheet of Melinex®, a high quality polyester film), and easily drillable; b) on which it is possible to mark references for the correct repositioning of the mask on the surface of the artwork and of the instrument for acquiring the measurements.
3. The measurement mode.

This paper presents the experience gained over five years of monitoring a panel painting (439.5 cm x 295 cm) by Giorgio Vasari depicting the 'Resurrection of Christ and Saints' (1568) in the basilica of Santa Maria Novella in Florence (Figs. 1 and 2).

Fig. 1. 'Resurrection of Christ and Saints' panel painting (1568) by Giorgio Vasari after restoration (photo by Claudia Gisela Reichold).

Fig. 2. Colorimetric measurements selected spots (photo by Claudia Gisela Reichold).

The artwork, on which the varnish had just been applied to finalize its restoration work, which therefore corresponded to time "zero" (T0), was deemed a perfect case study to validate the monitoring methodology of any observed color variations for the varnish-paint system. The possible causes of degradation of this system and monitoring of environmental parameters (temperature, relative humidity, pollutants, etc.) were considered not of interest in the definition of the monitoring methodology.

For the acquisition of the reflectance spectra, and the subsequent colorimetric calculation, a Konica-Minolta model CM-700d colorimeter and SpectraMagic NX software were used.

In particular, this work focuses on: a) the methodology developed to allow the repetition of measurement campaigns over time; b) acquired data processing; c) their meaning in relation to the monitoring over time of the optical properties of the varnish and the pictorial film; d) the problems associated with the implementation of these monitoring campaigns.

2. "Resurrection of Christ and Saints" (1568) by Giorgio Vasari

Giorgio Vasari was commissioned by Cosimo I de' Medici to thoroughly renovat of Santa Maria Novella in Florence following the new orientations of the Counter-Reformation. As part of this immense project, he painted the "Resurrection of Christ with Saints Cosmas and Damian, John the Baptist and Andrew" for the Basilica in 1568. Unfortunately, after ca 450 years the image of the wood panel painting was difficult to "read" due to layers of environmental deposits such as black carbon from hundreds of thousands of candles in centuries, yellowed and oxidized varnishes and altered materials from "refreshing treatments", overpaintings, etc. Therefore, as part of the long and complex restoration intervention dictated by the conservation conditions of the work, a new respectful cleaning was deemed necessary. The severest problem was caused by previous aggressive cleaning causing the loss of original paint material which had irremediably disfigured the image. To hide this serious damage, entire sections of the work had been covered in black oil paint, upsetting not only the chromatic values, but also the iconographic meaning and compositional spatiality. During this last restoration, after having recovered the original color fragments, the aim was to identify and rediscover the potential unity of the work; following in-depth studies and long reflections and always having Vasari's drawing as a guide and confirmation the aim of the retouching was, in tip of the brush, to gradually recover the values distorted by previous interventions, thus seeking a new balance. As reported earlier, the time at which the varnish was applied to the paint film at the conclusion of the restoration is considered the T0 of the monitoring of the varnish-paint system. In this way, chromatic values and spatiality of the precious mannerist work were restored, once again allowing a truthful and correct reading, and to enjoy its full beauty.

3. Methodology

Eight measurement areas were selected at the bottom of the panel painting. This choice was made for logistical reasons since the artwork, after its restoration, had been recollocated in its original position, in the fourth altar of the west aisle wall of the basilica (basal part of the painting placed approximately 150 cm from the floor). Since it was not possible to use scaffolding or other structures to reach the central or top areas of the painting, and for the distance imposed by the altar itself, only the basal parts of the work were considered for this study. Furthermore, the selection of the areas to be analyzed was determined by the possibililty to have colors that were as homogenous as possible and with hues that were more chromatically sensitive to variations in the transparency of the varnish. This led to the choice of light color tones with blue-green and magenta-lilac shades.

Measurements were performed on: 25th January, 2019 (T0); 24th July, 2019 (T1); 13th February, 2020 (T2); 21st July, 2020 (T3); 22nd June, 2021 (T4); 15th March, 2022 (T5); 3rd April, 2023 (T6); 2nd February, 2024 (T7).

All measurements were performed by the same operators, including the positioning of both the masks and the colorimeter on the measurement points. Five measurements were acquired for each spot, assuring to reposition the instrument on the mask at each single acquisition. The instrumental parameters were set as follows: 8 mm aperture (MAV), specular component excluded (SCE) and included (SCI). It was decided to consider the two measurement geometries in order to highlight any changes in the filmogenic layer attributable to physical changes in the film (e.g. gloss reduction over time). Colorimetric data were calculated for the 10° Supplementary Standard Observer and D65 Illuminant in the CIEL*a*b* 1976 color space. The L*, a* and b* parameters obtained from the five acquisitions for each measurement were averaged for each spot and the maximum error was also calculated to define the validity of the data obtained. Colour differences were then calculated using the CIEDE2000 colour difference formula (ΔE_{00}) (Sharma et al., 2005). The evaluation of the accuracy and repeatability of the measurements within a specific measurement campaign was made by considering the values of the maximum errors for the three colorimetric parameters. In the case of homogenous paint layer, when these errors are small (generally < 0.5), it means that the repositioning of the instrument on the mask was done with good precision. The accuracy and reproducibility of mask positioning, on the other hand, was verified by observing the trend of the color variation values over time. If this tendency presents a progressive and constant trend over time, without marked fluctuations, it can be assumed that this operation has been performed correctly and is therefore reproducible.

4. Results

The results obtained at the end of the first five years of monitoring are presented and discussed below. Particular attention has been given to their evaluation in relation to the methodology of acquisition of colorimetric data on the artwork.

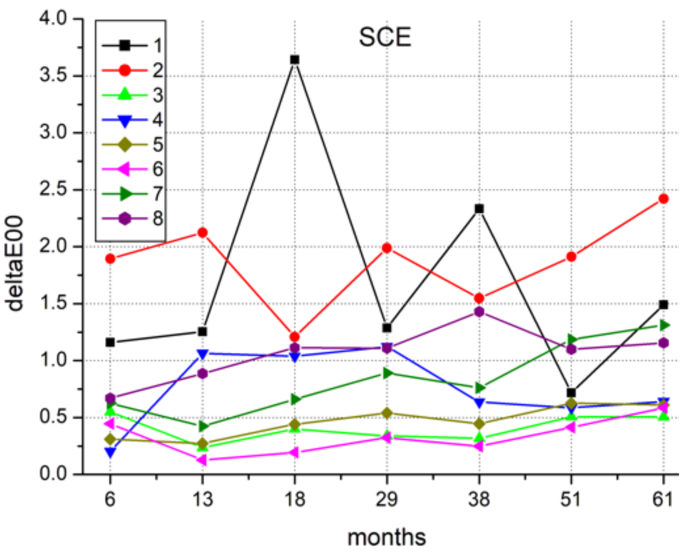


Fig. 3. Trend of ΔE_{00} values of measurements in SCE mode for selected areas.

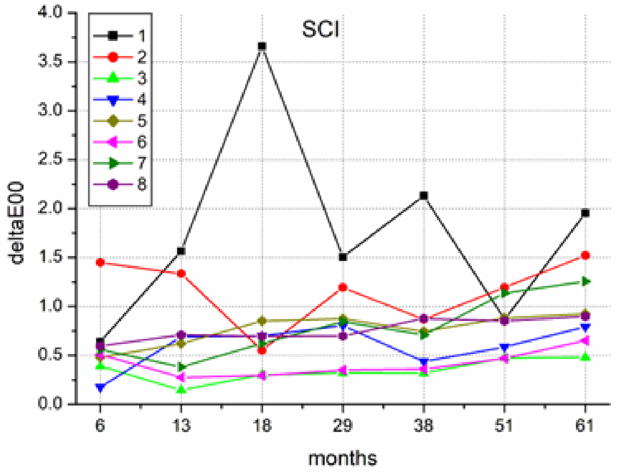


Fig.4. Trend of ΔE_{00} values of measurements in SCI mode for selected areas.

From the data shown in Table 1, it is evident that measurement points 3-8 do not show appreciable changes over the time period considered. In fact, they generally present values of $\Delta E_{00} < 1$, reaching a maximum value of ΔE_{00} around 1.5. Furthermore, the trend of ΔE_{00} values during monitoring is constant without marked fluctuations or trends. For these measurement zones, observing the average data and maximum errors for the three colorimetric parameters of each measurement set, it can be argued that the positioning of both the instrument and the masks were performed optimally. In fact, the maximum errors for each measurement set for the three colorimetric parameters are overall low (< 0.5), and the color variation values over time show a rather regular upward trend (Table 1). This trend indicates a slight variation in the color values of the film-forming layer, even if to date it is not visually perceptible.

With regard to measurement points 1 and 2, the values found are difficult to interpret. In fact, the ΔE_{00} values calculated for the spot 1 show a strong variation during monitoring with a fluctuating trend. As shown in Figures 3 and 4, the SCE mode ΔE_{00} values are at T1 slightly above 1, then rise at T3 with $\Delta E_{00} > 3$, then return at T4 to values similar ($\Delta E_{00} = 1.29$) to the initial ones, rise abruptly at T5 ($\Delta E_{00} = 2.33$), then fall at T6 to values below those measured at T1 ($\Delta E_{00} = 0.72$) and finally rise twice as high at T7 ($\Delta E_{00} = 1.49$). The same fluctuating trend was recorded for the measurements in SCI mode, although in this case the initial differences were smaller than those observed in SCE mode. This same behavior is also observed in Table 2, where the L*, a* and b* values over time show fluctuating trends, indicating a mask repositioning procedure that is not always correct on the area of interest. In fact, even on surfaces with relatively uniform colors, small movements of the measurement area can lead to different colorimetric values.

For measurement zones 1 and 2, when observing the maximum errors for each colorimetric parameter in each set of measurements, it can be seen that they are > 0.5 (this is evident in the measurement at T0). This indicates that the repositioning of the instrument on the mask may not have been done with good precision.

			ΔE_{00}							
difference	**months**		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
T1 - T0	6	SCI	0.64	1.45	0.39	0.17	0.48	0.51	0.56	0.60
		SCE	1.16	1.90	0.55	0.20	0.31	0.45	0.62	0.67
T2 - T0	13	SCI	1.56	1.34	0.15	0.69	0.62	0.28	0.38	0.71
		SCE	1.25	2.12	0.23	1.06	0.27	0.13	0.42	0.89
T3 - T0	18	SCI	3.66	0.55	0.30	0.70	0.85	0.29	0.62	0.70
		SCE	3.64	1.21	0.40	1.04	0.44	0.19	0.66	1.11
T4 - T0	29	SCI	1.50	1.19	0.32	0.81	0.88	0.35	0.85	0.70
		SCE	1.29	1.99	0.34	1.12	0.54	0.32	0.89	1.11
T5 - T0	38	SCI	2.13	0.87	0.32	0.44	0.75	0.36	0.71	0.88
		SCE	2.33	1.55	0.32	0.64	0.45	0.25	0.76	1.43
T6 - T0	51	SCI	0.87	1.19	0.47	0.59	0.88	0.47	1.14	0.85
		SCE	0.72	1.91	0.51	0.59	0.63	0.42	1.19	1.10
T7 - T0	61	SCI	1.95	1.52	0.48	0.79	0.92	0.65	1.26	0.90
		SCE	1.49	2.42	0.51	0.64	0.61	0.59	1.31	1.16

Table 1. Color difference (ΔE_{00}) of the eight measured spots.

	T1 - T0		**T2 - T0**		**T3 - T0**		**T4 - T0**		**T5 - T0**		**T6 - T0**		**T7 - T0**	
	SCI	**SCE**	**SCI**	**SCE**	**SCI**	**SCE**	**SCI**	**SCE**	**SCI**	**SCE**	**SCI**	**SCE**	**SCI**	**SCE**
	Spot 1													
ΔL	0.24	0.96	-1.68	-1.26	-3.93	-3.71	-1.67	-1.34	-2.28	-2.34	-0.75	-0.21	-2.05	-1.39
max error	1.56	1.50	1.67	1.67	1.25	1.37	1.17	1.17	1.16	1.09	1.43	1.13	1.22	1.41
Δa	-0.59	-0.81	0.61	0.56	1.34	1.44	0.32	0.32	0.79	1.01	-0.06	-0.22	0.52	0.36
max error	0.70	0.77	0.80	0.90	0.56	0.71	0.52	0.62	0.49	0.61	0.68	0.61	0.53	0.62
Δb	0.12	-0.01	0.37	0.42	0.4	0.52	0.49	0.53	0.65	0.79	0.71	0.76	1.01	1.07
max error	0.08	0.11	0.08	0.16	0.06	0.13	0.04	0.11	0.05	0.14	0.05	0.12	0.06	0.11
	Spot 2													
ΔL	1.50	1.84	1.38	2.09	0.50	1.14	1.21	1.93	0.78	1.50	1.24	1.89	1.47	2.31
max error	2.03	1.77	1.27	0.94	1.25	0.89	1.34	0.93	1.23	0.87	1.22	0.81	1.22	0.89
Δa	-0.26	-0.36	-0.25	-0.36	-0.25	-0.38	-0.19	-0.34	-0.23	-0.35	-0.02	-0.11	-0.26	-0.41
max error	0.17	0.18	0.17	0.18	0.18	0.20	0.19	0.16	0.17	0.18	0.17	0,17	0.17	0.17
Δb	0.10	0.28	0.04	0.14	-0.18	-0.12	0.27	0.36	0.39	0.04	0.31	0,43	0.59	0.67
max error	0.91	0.67	0.52	0.30	0.54	0.31	0.53	0.28	0.89	0.26	0.49	0,23	0.48	0.26

Table 2. Differences of color values (ΔL^*, Δa^*, Δb^*) over time and sum of maximum deviations for measurement points 1 and 2.

5. Conclusions

In general, colorimetric measurements are particularly useful for following the cleaning and inpainting procedures on polychrome works, as they make it possible to monitor the color over time and reveal any chromatic variations in the pictorial film. The measurement methodology is quick and easy to apply, but has numerous variables that must be taken into account in order to carry out reliable and repeatable measurements. It is important to take into account errors associated with the methodology itself and those associated to the operator carrying out the measurement.

In terms of repositioning the instrument on the mask, the evaluation of the accuracy and repeatability of the measurements, within a specific measurement campaign is done by observing the values of the maximum deviations for the three colorimetric parameters. With the exception of points 1 and 2, the maximum deviations found were negligible (< 0.5), meaning that the repositioning was performed with good precision. The accuracy and reproducibility of the mask positioning is instead evaluated by observing the trend of the color variation values over time. Also in this case, with the exception of points 1 and 2, the trend proved progressive and constant over time, without marked fluctuations. These measurements therefore appear to be correct and reproducible. For points 1 and 2, on the other hand, higher maximum deviations and a fluctuating trend in the ΔE_{00} value were recorded; it can be assumed that the data were probably affected by errors in repositioning the instrument on the mask and/or errors in repositioning the mask over the measurement area. As regards the chromatic variation of the film-forming material, the results obtained confirm what is visually observable, namely that the applied varnish does not appear to have undergone any appreciable change over the course of five years.

The results obtained are certainly a great incentive to continue this monitoring in the coming years to assess whether the varnish chromatic property is changing. In addition, it is intriguing to understand the role of the underlying paint film in highlighting this change.

6. Conflict of interest declaration

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

7. Funding source declaration

This study was done without any external funding.

8. Acknowledgment

C. G. Reichold deeply thanks Fathers Daniele Cara OP, Aldo Tarquini OP and Graziano Lezziero OP, Presidents of the Opera per Santa Maria Novella, the domenican community of SMN; Dr. Andrea Pessina, Superintendent of Florence, Pistoia and Prato, for the authorization of the restoration; Dr. Anna Bisceglia, curator of 16th century painting, Gallerie degli Uffizi, past responsible for the protection of the Santa Maria Novella District for the historical-artistic contribution during the restoration; Dr. Anna Mitrano, Vice-prefect representing FEC, Ministry of the Interior; Arch. Francesco Sgambelluri, construction supervisor for Santa Maria Novella. A special thanks to Sirpa Salenius for her support in the acquisition of the colorimetric data.

9. Short biography of the author(s)

Claudia Gisela Reichold - Trained in Germany, the United States and Italy, she is a Ministry of Culture (MiC) qualified conservator and has worked for 25 years on masterpieces of Museums and Churches in Florence, Italy (Uffizi Galleries, Bargello Museums, Santa Maria Novella and Ognissanti) and for private collections worldwide. After almost 10 years of teaching at University of Dubrovnik, Croatia she collaborates with Italian and American educational institutions and is President of the cultural association ExperianceArt.

Irene Pieralli - Graduated in Science and Materials for Conservation and Restoration of Cultural Heritage from the University of Florence in 2022. Her master thesis work focused on the study of an alternative formulation of Laropal A81 varnish for paintings, free of aromatic solvents and therefore safer for the health of operators and the environment. After graduation she continued her research activity producing various publications, and in 2023 she worked as a conservation scientist for the Florence Museum of Prehistory, supervising the scientific investigations for the façade of the Abbey of San Miniato al Monte in Florence.

Elisa Gualini – Research fellow at Department of Chemistry, University of Florence, Sesto Fiorentino (Florence). She holds a master's degree in Science and Materials for Conservation and Restoration of Cultural Heritage from the University of Florence. She conducted her master's thesis research on diagnostic techniques, in particular on FORS, XRF, FT-IR, multiband and hyperspectral imaging applied to historical rose-windows. She was a visiting researcher at the insiTUMlab of the Technical University of Munich.

Serena Hirsch - Scientific collaborator at Centro Conservazione e Restauro La Venaria Reale, Turin. She holds a master's degree in Science and Materials for Conservation and Restoration of Cultural Heritage from the University of Florence. She conducted her master's thesis research on diagnostic techniques, in particular on multiband imaging applied to paintings. She was visiting researcher at Universitat Politécnica de València.

Serena Morrocchesi - Research fellow at Department of Chemistry, University of Florence, Sesto Fiorentino (Florence). She holds a master's degree in Science and Materials for Conservation and Restoration of Cultural Heritage from the University of Florence. She conducted her master's thesis research on diagnostic techniques, in particular on FORS, XRF, FT-IR, Raman, multiband and hyperspectral imaging applied to Purple manuscripts. She was a visiting researcher at the insiTUMlab of the Technical University of Munich.

Marcello Picollo - PhD in Photonics from the University of Eastern Finland (UEF), Faculty of Science and Forestry, Joensuu (Finland) and graduated in geology from the University of Florence, he is a researcher at the Institute of Applied Physics "Nello Carrara" of the National Research Council of Italy (IFAC-CNR), Florence. He has been working on spectroscopic investigations of works of art since 1991 and his main research focus is on artists' material characterization using non-invasive spectroscopic and imaging techniques.

Licensing terms

References

Aldrovandi, A., & Picollo, M. (1999). Metodi di documentazione e indagini non invasive sui dipinti. Collana i Talenti. Padova (I): Il Prato.

Bacci, M., Casini, A., Cucci, C., Picollo, M., Radicati, B., & Vervat, M. (2003). Non-invasive spectroscopic measurements on the Il ritratto della figliastra by Giovanni Fattori: identification of pigments and colourimetric analysis. Journal of Cultural Heritage, 4(4), 329-336. doi.org/10.1016/j.culher.2003.09.003.

Bestetti R. (2020). La verniciatura dei manufatti policromi: dalle vernici tradizionali alle resine a basso peso molecolare, Collana i Talenti. Padova (I): Il Prato.

Chercoles, R., De Tapol, B., Ordoñez, A., & Domedel, L. (2011) Low molecular weight varnishes. Interview to E. René de la Rie, National Gallery of Art, Washington, DC., Ge-conservación No. 2, pp. 33-42.

de la Rie, E.R., (1992). Stability and Function of Coatings Used in Conservation, National Gallery of Art, Scientific research department, Washington DC 20565, USA.

Johnston-Feller, R. (2001). Color science in the examination of museum objects: nondestructive procedures. Getty Publications.

Maines, C.A., & de la Rie, E.R., (2005). Size-exclusion chromatography and differential scanning calorimetry of low molecular weight resins used as varnishes for paintings, Progress in Organic Coatings 52, pp. 39-45.

Phenix, A., (1993). Artist's and conservation varnish, an historical overview, in Varnish teory and practise, ABPR 50th anniversary Conference, a cura di Padfield S., pp. 12-26. Association of British Picture Restorer.

Pinna, D., Galeotti, M., & Mazzeo, R. (Eds.). (2009). Scientific examination for the investigation of paintings. A handbook for conservator-restorers. Firenze (I): Centro Di.

Stoner, J. H., & Rushfield, R. A. (Eds.). (2012). The conservation of easel paintings. London: Routledge.

Sharma, G., Wu, W., & Dalal, E. N. (2005). The CIEDE2000 color-difference formula: Implementation notes, supplementary test data, and mathematical observations. Color Research & Application, 30(1), 21-30.

Vila, A. & Murray, A. (Eds.). (2022). Diagnosis: Before, During, After, Collana Conservation 360°, No. 2, Valencia (E): Universitat Politècnica de València.

The polychrome surfaces of Apulia's monuments between the 19th and 20th centuries.

The contribution of color to the spread of neo-medievalism and the creation of national identity

Maria Antonietta Catella[1]

[1] *Architect, Specialist in Architectural and Landscape Heritage, PhD. catellamariaantonietta@gmail.com*

Corresponding author: Maria Antonietta Catella (catellamariaantonietta@gmail.com)

ABSTRACT

As is known from studies published in recent years, starting from the second half of the 19th century, profound transformations affected the main monuments of the newly formed Kingdom of Italy. In this revolutionary climate, the definition of national identity was pursued through cultural actions, including the completion of restoration works of religious buildings. Are revived the characteristics of Romanesque and Gothic architecture, characterised in some cases by polychrome decorative surfaces and two-colour marble cladding. This triggered a process of rediscovery of the chromatic and ornamental aspects and medieval stylistic features, which was realised in the representative restorations of the neo-medieval period and in the design of neo-Romanesque and neo-Gothic buildings.

Within this complex historical framework of artistic renewal are the reasons that motivated the choice of a retrospective trend and the creation of a style, the reverberations of which also manifested themselves in Apulia, taking on a regional character. Real campaigns were inaugurated to eliminate Baroque decorations from monuments in order to rediscover or reinvent the "Apulian Romanesque". Sometimes this was done by simply removing the rich 17th and 18th century decorations. At other times, modernisation and "embellishment" operations were carried out with the creation of stuccoes and decorative plasterwork, now disengaged from structural logic but simulating polychrome and two-colour walls. They were made by alternating different materials or marble coverings of different colours.

This paper aims to examine the role of the colour of architectural surfaces in the creation of regional and national identity. It first illustrates the well-known "embellishments" of Apulian medieval churches designed by Federico Travaglini in the Cathedrals of Altamura and Troia. It continues with an analysis of the decorations created in the Cathedral of Conversano and in lesser-known buildings such as the rural Church of San Giorgio Martire in Bari. It concludes with a presentation of the decorations made in the neo-medieval churches of San Giuseppe and Immacolata in Bari and Sacro Cuore in Brindisi, built in the 20th century. The aim of this paper is to illustrate the extent of the spread of an architectural expression that was inaugurated in the second half of the 19th century and came to maturity in the first decades of the 20th century.

 DOI: 10.23738/CCSJ.160204

KEYWORDS Bichromy and polychromy, Neo-Medievalism, Apulian neo-Romanesque and neo-Gothic, History of restoration.

RECEIVED 11/08/2024; **REVISED** 23/09/2024; **ACCEPTED** 02/11/2024

1. Introduction

In recent decades, a renewed interest has marked studies and research on the artistic currents of the 19th century, which had been negatively judged in the international context since the 1920s. Since the 1970s, scholars' attention has focused on neo-medievalism and the neo-Renaissance: between the post-unification phase and the Great War, these artistic expressions contributed to the foundation of a new cultural hegemony that made it possible to overcome the many regional identities and to create the Kingdom of Italy characterised by a definite nationalist sentiment. It was in this half-century, marked by the debate on national style and regional identity (Neri, 1997), that the propensity toward the recovery of the past was manifested through the neo-Medieval restoration work promoted by Pietro Selvatico Estense. At the same time, Camillo Boito promoted a versatile design approach following the principles of Neo-Romanesque and the models of Lombard architecture (Mangone, 2015). Studies on medieval architecture and the writings of the two authors contribute to the diffusion on the national territory of ideas and models from Germany, France and England characterizing European Romanticism and reworked by Italian neo-Medievalism (Zucconi, 1997). The Middle Ages thus become the reference era from the ethical point of view, the era of highest expression of moral and social values that takes on a strong symbolic connotation (Zucconi, 1997; Neri, 1997). «Taking the Middle Ages as a model therefore means rediscovering one's national roots and, at the same time, giving religious depth back to architecture» (Zucconi, 1997, p. 29).

2. In search of national identity: the rediscovery of the "colored Middle Ages"

Internationally, the intention of overcoming regional specificities and creating the official national style of the Kingdom of Italy is pursued through the adoption of neo-Renaissance in the realization of the public architecture representative of the new State in Rome Capital and in the palaces of the Province and Prefecture of different cities (Neri, 1997; Mangone, 2015). Neo-medievalism contributes to the creation of a national style by becoming the representative style of Christianity and place of worship. «Gothic is considered the "style" most suitable for Churches by all Nineteenth-century critics, starting with the diffusion in Italy of Chateaubriand's volume *Le génie du Christianisme*, the true manifesto of early French medievalism, to which the position of Pietro Selvatico Estense is directly linked» (Picone, 1996, p. 59). Thus, numerous churches, new convents - often refounded by previously suppressed religious orders - and neo-Romanesque and neo-Gothic cemeteries were built in the Kingdom of Italy. They are differentiated by the specific material, formal and chromatic peculiarities of the plural regional identities that overlap the neo-Medieval style (Neri, 1997). «Each region was going to choose "its" Middle Ages, that is, the one that in regional or even local history had played a decisive role» (Billi, 2014, p. 2).

2.1. *The French contribution to the rediscovery of the "coloured Middle Ages" in Italy*

It is France that holds the record for rediscovering the polychromy of architectural surfaces, contradicting the belief that had matured over the centuries that medieval buildings of worship were uniformly white. A new sensibility aimed at the preservation of the most representative monuments is manifested by the new French preservation organizations in the phase following the revolutionary vandalistic destruction. Alexandre Lenoir, Prosper Mérimée and Eugène Emmanuel Viollet-le-Duc rediscover medieval polychrome surfaces hidden by white plasterwork created in later centuries (Fachechi, 2014; Fachechi, 2016; Pollini, 2017). «It became clear then, in Nineteenth-century France, that between Antiquity and the Middle Ages there was a kind of "polychrome link", that is, that if Antiquity had combined form and color in its art, the Middle Ages had continued and enhanced this union, reaffirming the unity between architecture, sculpture and painting and finding in color an element of identity. Thus it was that many architectures were restored and freed from all those superfetations that had made them unrecognizable over the centuries, they were freed from the unreal whiteness, from the pale semblance that neoclassicism had given them, which had praised absolute white [...]» (Fachechi, 2014, p. 100).

Certainly, the revival of medieval polychromatic characters asserted itself in the Italian and European art world with the rediscovery of the original coloured surfaces documented with studies and illustrations. This is what emerges from the drawings and watercolours implemented by the *pensionnaires*, Eugène Viollet le Duc and Jakob Ignaz Hittorff during their Italian visits. The latter two visited the Basilica of Assisi, the Cathedrals of Messina, Florence, Genova, Monreale and Siena (Savorra, 2005; Billi, 2014; Varagnoli, 2017; Pollini, 2017). On several occasions, Viollet le Duc has stated that, during his travels in Italy, he observed medieval monuments more closely than classical ones, dwelling more on the decorative rather than the structural aspects (Romeo 2013; Varagnoli, 2017, p. 114). Viollet le Duc's influence on the development of Italian stylistic restoration was considerable. «Until the moment of national unification (1861), Viollet's influence in Italy was part of the more general habituation to neo-medieval models that were spreading throughout Europe. However, Italian adherence appears limited to decorative and all in all marginal aspects and, compared to other European countries, the codification of medieval styles is less rigorous» (Varagnoli, 2017, p. 117). In the post-unification phase, Viollet le Duc's influence is more noticeable, having been consulted several times on the completion of medieval monuments that contributed to the spread of polychrome architecture in the Kingdom of Italy. They are implemented, for example, by Niccolò Matas on the unfinished bichromatic façade of the medieval Florentine Church of Santa Croce, and it is no coincidence that Viollet le Duc was consulted on the occasion of the competition for the completion of the polychromatic façade of Santa Maria del Fiore in Florence, won by Emilio De Fabris (Varagnoli, 2017, p. 119). In the last quarter of the 19th century, similar interventions were carried out in other regional contexts. This is attested by the Lombard Churches of San Simpliciano, San Marco, Sant'Eustorgio and Santa Maria del Carmine in Lombardy - curated by Carlo Maciachini -, the Church of San Donato in Genova, restored by Alfredo d'Andrade, and the Church of San Francesco in Bologna reconstructed in its presumed original form by Alfonso Rubbiani. The reconstruction of the façade of Amalfi Cathedral is instead entrusted to Errico Alvino (Fachechi, 2014; Fachechi, 2016; Varagnoli, 2017; Savorra, 2018). All these interventions testify to a real phenomenon that spread in Italy between the 19th and 20th centuries. They are examples of the reinterpretation of the pre-existing representations of the political power of the Middle Ages and were implemented in function of the creation of national identity, with a clear intent to educate Italians. Thus, the moral and cultural re-appropriation of heritage anticipated the monumental one (Savorra, 2018). «However, for those who were about to put their mark on millennia-old religious architecture, the first step was to identify and understand the origins of such "Italian" monuments, as well as to determine "what" identity could represent Italy and the nascent consciousness of Italians» (Savorra, 2018, p. 16). Thus, next to the real Middle Ages arises an imagined Middle Ages that aims to affirm the continuity of the Nineteenth century from the glorious past centuries (Mangone, 2018). «The filtering action of the Nineteenth Century proceeds according to a pincer pattern: on the one hand the work of ideal sifting, on the other that of real transformation» (Zucconi, 1997, p. 36).

2.2. *The revival of polychromy: italian influences on english victorian architecture*

Probably the rediscovery of polychromatic Italian architecture of the Middle Ages - particularly that of northern Italy - influenced the experimentation and revival of English polychromy in the Victorian era. Architects William Butterfield and George Edmund Street rediscovered the Anglo-Saxon polychromy exhibited in bands in two medieval churches in Northamptonshire (Jackson, 2004; Paine, 2011, p. 13). At the same time, in the first half of the 19th century, a number of British architects and art historians carefully observed the colourful surfaces of Venetian and Tuscan Gothic monuments and Pisan Romanesque and documented this feature with sketches and itinerary accounts (Paine, 2011, pp. 5-6; Chatterjee, 2017). This is attested by the writings of John Ruskin - *The Seven Lamps of Architecture* and *The Stones of Venice* - and George Edmund Street - *Brick and Marble in the Middle Ages: Notes of Tours in the North of Italy* -. The study of colour allowed architectural theorists to reflect on the concepts of form and structure of buildings. It gave rise to a debate between the supporters of the polychromy of the "encrusting school" - purely Venetian - and the "constructional school" - prevalent in the Lombardy area - (Street, 1855, p. 282). If the former was conceived with the aim of concealment and camouflage of structural and constructional aspects, the latter is intended to show clarity and the true way of building (Jackson, 2004; Paine, 2011, p. 8; Chatterjee, 2017, pp. 13-14, pp. 17-18).

The deceptive and truthful duality of medieval polychrome surfaces constituted a starting point for the theoretical elaboration of 19th-century restoration, which later also influenced Italian exponents: the paradigm of "truth", argued by Augustus Welby Northmore Pugin and John Ruskin constituted the moral objective of religious research, which could be pursued in the architecture of the Victorian period with "constructional polychromy" (Chatterjee, 2017, pp. 13-14). Between the 1840s and 1870s, the use of polychrome bricks - mainly red and black - in the construction of new churches became widespread in the Anglo-Saxon cultural context. The use of brick in the revived church showed that the revival was not simply a nostalgic return to the past, but constituted a clear link with the contemporary industrial age (House, 1963, p. 112). From 1860 onwards, almost all urban churches were built of brick, often combined with stone elements. They were characterised by banded surfaces and a wide range of geometric motifs, polychrome inlays and decorative experiments. Emblematic are the buildings designed by William Butterfield between the High Victorian (1850-1870) and Late Victorian (1870-1900) periods: the Church of All Saints, Margaret Street, London; the College and Church of the Isle of Cumbrae; Balliol College Chapel, Oxford; the Churches of St Alban's, Holborn, Holy Cross, of Holy Saviour, Hitchin, of St. Augustine, Queen's Gate, Kensington, of All Saints, Babbacombe, Devonshire; the Rugby School, Rugby Parish Church and Keble College, Oxford (House, 1963). In the same period, "constructional polychromy" was experimented by other architects such as Henry Woodyer - in St Augustine, Haggerston - (House, 1963, p. 119), Richard Norman Shaw - in New Scotland

Yard, London - Alfred Waterhouse - in the Natural History Museum, London - (Paine, 2011, p. 6). The architecture designed by William Butterfield caught the attention of contemporaries and the All Saints Church, Margaret Street, London, was praised in the pages of the *Ecclesiologist*: «'He was the first to show us that red brick is the best building material for London, and to prove to us that its use was compatible with the highest flights of architecture. In the matter of bonding his red brick with black and other colours, we chiefly admire his moderation. His numerous imitators in this popular style of constructional polychrome have often overlooked his example of discretion. [...] In this impressive church, in spite of smallness of scale, he has approached the sublime in architecture'» (House, 1963, pp. 114-115). The All Saints Church, Margaret Street, London, also fascinated George Edmund Street, who called «'it is not only the most beautiful, but the most vigorous, thoughtful and original of them all'» (House, 1963, p. 114) and used it as a model for the designs of the Churches of All Saints, Boyne Hill, Maidenhead, and St James the Less, Pimlico, Westminster (House, 1963, p. 114; Paine, 2011, p. 6). Later, between 1873 and 1880, Street reproduced the polychrome surfaces in the Church of St Paul's Within the Walls in Rome (Blanchard, 1991).

One of the most distinguished proponents of the polychromy elaborated by the "encrusting school" was John Ruskin. The alternating use of horizontal bands of stone and brick not only evoked geological stratification (Paine, 2011, p. 7; Chatterjee, 2017, p. 14), but also allowed the art critic to reflect on the decorative aspects of polychromy, "ornament" and the principles of textiles, much discussed in the Victorian era, and to contribute to new developments in architectural theory (Chatterjee, 2017, pp. 17-18). Venetian and Tuscan architectures with polychrome surfaces that concealed the structural and spatial aspects of buildings were compared to clothed bodies. Their coverings were reminiscent of woven fabrics, made of alternating coloured threads. For John Ruskin, the beauty of ornament is revealed by some medieval Italian architecture: the Baptistery in Florence, described as the «'central building of European Christianity'» and the Doge's Palace at Venice, defined as the «'central building of the world'» and «'a model of all perfection'» (Chatterjee, 2017, p. 18).

2.3. *Clarity and camouflage of Italian neo-medieval architecture*

As was the case in England, in Italy polychrome surfaces are experimented not only in the restoration and completion of mediaeval architecture, but also in new buildings. The «counterpoint of materials, between brick and stone, and of color contrasts, between the brown and the light of the cladding» (Zucconi, 2016, p. 15) also recurs in Camillo Boito's new civil constructions of the Gallarate hospital, the Palazzo delle Debite and the school complex of the so-called "Reggia Carrarese" in Padua (Zucconi, 2016). It is therefore no coincidence that the "counterpoint of materials" - experimented with great expressive, figurative and scenographic freedom - scans the elevations of the buildings constituting the monumental cemeteries of the Verano in Rome, Gallarate and Milan (Neri, 1997), highly symbolic for the civic values held. In the latter, it is especially the Famedio that represents the «Lombard mixed with Byzantine elements» (Selvafolta, 2007, p. 187). Recalling many styles and eras, the building illustrates the echoes of neo-medievalism: «from the Romanesque-Pisan to the Comacine for the vestments lined with alternating white and dark red bands, from Gothic *tout-court* for the crowning cusps, to florid Gothic for the rose windows and tracery motifs, from Byzantine for the mosaics, to Ravenna for the carvings in the marble and the enveloping capitals. As if the traces of a long-lasting and geographically extensive Middle Ages had been imprinted on the Famedio [...]» (Selvafolta, 2007, p. 201).

In other cases, however, decorative and chromatic peculiarities are freed from structural and material logic, and imitative and inventive intentions overlap and blur. It is visual perception, the idea of the work, that constitutes the prerogative of the new architectures, while the material takes on an exclusively instrumental value. This is what is revealed by the neo-Gothic Church of the Sacred Heart of the Suffrage in Rome, «whose concrete façade re-proposes the well-known Tuscan bichromy with horizontal white/green grey bands» (Fachechi, 2016, p. 26). On the other hand, in the interior, the white/grey-red two-tone colour scheme is differentiated between the load-bearing parts of the columns and the ribs of the vaults - decorated with alternating bands of brick and grey stone - and the closing parts of the walls, marked by alternating painted bands. Making itself independent of the masonry support, colour can thus take on a function of "embellishment" of surfaces and be experimented in free stylistic variations and ornamental cycles. This can be seen in the interior surfaces of the Cathedral of Reggio Calabria - rebuilt in neo-Romanesque forms following the earthquake of 1908 - on which the rows of masonry are painted. Other examples are the coloured plasters of the twentieth-century Church of the Immaculate Conception and San Giovanni Berchmans in Rome or the Churches of Sant'Antonio da Padova in Turin and Sant'Antonio da Padova dei Minori Osservanti in Bologna. They were built in the last decades of the 19th century to emphasise, with a new decorative figurativeness inspired by medieval origins, the renewed presence of the minor orders in the Kingdom of Italy.

3. Neo-medieval Apulia between "embellishments", liberating operations and new creations

Between the Nineteenth and Twentieth centuries, echoes of the neo-Medieval style also manifested themselves in Apulia, contributing to the creation of a regional style. The rediscovery of the glorious past and of the regional cultural identity, identified in the "Apulian Romanesque", is sometimes pursued with transformation and "embellishment" operations experimented on the pre-existing buildings, others with the construction of new neo-Romanesque and neo-Gothic buildings. At other times, the destruction of the "encrusting baroque" (Guarnieri, 2007, p. 13) is carried out, aimed at revealing the presumed original medieval appearance of Apulian monuments hidden by the stratifications and decorative apparatuses dating back to the 17th and 18th centuries.

3.1. *Federico Travaglini and the "immegliamento" of the Cathedrals of Altamura and Troia*

Neapolitan cultural hegemony, still in force in the mid 19th century in Apulia, is attested by the "embellishments" of the Cathedrals of Altamura and Troia, designed by the Neapolitan architect Federico Travaglini (Civita, 1995; Picone, 1996; Picone, 2000). He became well known on the restoration scene of the time following the neo-Gothic transformation of the Church of San Domenico Maggiore in Naples, which was received with great enthusiasm by the public (Picone, 1996). Transposing only theoretically the precepts of Eugène Viollet le Duc due to insufficient philological and historical-critical preparation, the restorations conducted by Federico Travaglini took the form of operations not fully in line with the idea of restoration in style (Picone, 1996), that is, in interventions of «"immegliamento", understood as adaptation of the building to the aesthetic and taste canons of Naples in the second half of the Nineteenth century, oscillating between classicist and eclectic tendencies. It is that "retrospective orientation", understood as attention to the ways of the past, 'which is expressed through actions that tend to a further development of the architectural work, through operations of real design […]'» (Picone, 1996, p. 59) aimed at the restitution of a harmonious figurative unity. In this vision of restoration - aimed at enhancing the visual perception of the overall image with respect to structural and material sincerity and inspired by the "colored Middle Ages" -, decorative and chromatic aspects assume great importance.

In the Cathedral of Altamura, which still retains Travaglini's "immegliamento" interventions carried out between 1854 and 1864, colour is the undisputed protagonist (Fig. 1). This is also testified by photographs taken by Romualdo Moscioni between 1891 and 1892 and currently held in the Photo Library of the Kunsthistorisches Institut in Florenz - Max-Planck-Institut. In the last decade of the 19th century,

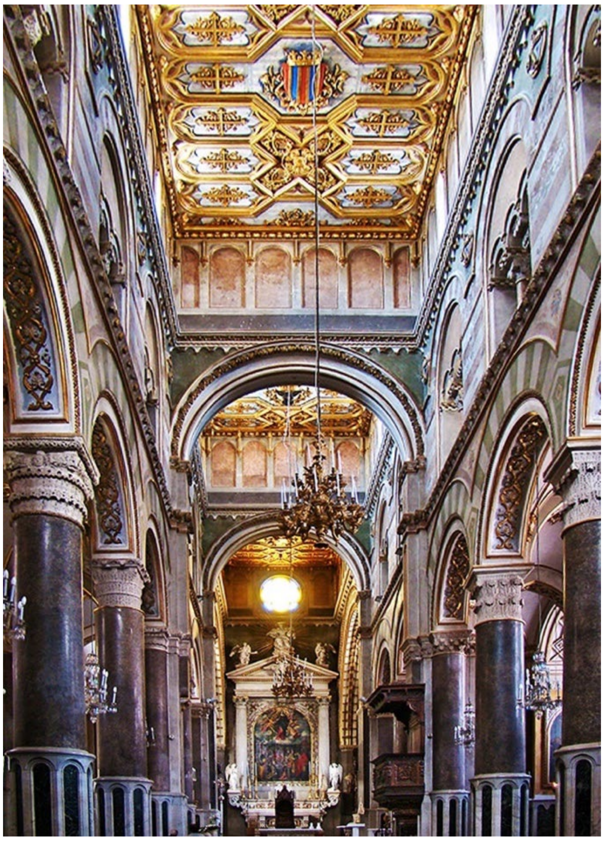


Fig. 1. Altamura, Cathedral. Current state of conservation (photography by Maria Antonietta Catella).

the chromatic peculiarity of the church was emphasised by the documentary photographer commissioned by the Ministry of Education to photograph the *Apulia Monumentale*, consisting of the most representative monuments of Apulia. In the Altamura Cathedral colour is manifested in paint, gilding, stained glass and horizontal bands decorated with phytomorphic motifs and white and pink two-coloured polished stucco in imitation of marble (Fig. 2). These decorations are similar to those created a few years earlier in the transept and apse of the Church of San Domenico Maggiore in Naples (Picone, 1996). The decorative apparatuses are made exclusively at the surfaces visible to the faithful along the ordinary liturgical route, leaving all other wall faces exposed instead. It is thanks to the horizontal bands that the arches of the naves and women's galleries are enhanced, marked by alternating white, green and pink stucco scores (Fig. 3). The marble decorations in green and white marble covering the lower portions of the pillars enrich the environment with the aim of restoring a harmonious whole of the religious space (Civita, 1995; Picone, 1996; Pollini, 2017). «The neapolitan experience remained a reference for a wealth of formal and decorative details that the architect himself drew on, also pointing out neapolitan workers of marble workers and decorators, who provided their services in the Altamura factory» (Civita, 1995, p. 330).

Fig. 2. Altamura, Cathedral, 1892. Left: detail of the stained glass windows. Photo: Kunsthistorisches Institut in Florenz – Max-Planck-Institut, photographer: Romualdo Moscioni. Right: detail of the decorations made only on the surfaces visible to the faithful along the ordinary liturgical route. The other surfaces are devoid of polychrome decorations. Photo: Kunsthistorisches Institut in Florenz – Max-Planck-Institut, photographer: Romualdo Moscioni.

Fig. 3. Altamura, the interior of the Cathedral in 1892. Photo: Kunsthistorisches Institut in Florenz – Max-Planck-Institut, photographer: Romualdo Moscioni.

Compared to the "embellishments" of the Churches of San Domenico Maggiore in Naples and Altamura Cathedral, the one directed by Travaglini on the Cathedral of Troia between 1857 and 1860 turns out to be more respectful of the pre-existences and the most important Baroque stratifications and implemented with less "vibrant" and evident decorations (Picone, 1996; Picone, 2000): «rather than restoring the factory to its "Romanesque nakedness", he seems interested in the re-functionalization of the Cathedral through the consolidation of the degraded parts and an operation of artistic enrichment of the whole space» (Picone, 1996, p. 112; Picone, 2000, p. 86). Some photographs taken in the last decade of the 19th century witness to the interventions carried out by Federico Travaglini at Troia Cathedral, which no longer exist (Fig. 4)

Fig. 4. Troia, the Cathedral in 1895. (William Henry Goodyear - Brooklyn Museum) Available at: https://it.wikipedia.org/wiki/Concattedrale_di_Troia#/media/File:S03_06_01_001_image_581.jpg (Access: 5 September 2023).

Following the demolition of the Baroque stone altars, the wide walls of the aisles allowed the architect to experiment with decorative motifs in polished stucco. Federico Travaglini's aim is to restore a unified image of the church, which is also in harmony with the exterior of the cathedral. For this reason, along the back walls of the nave, enriched by a Carrara marble base covering, the two-colour decorations present on the cathedral's exterior elevations are reproduced. These were made from the 12th century onwards by alternating white and grey/green stone elements (Fig. 5) and refer to the Pisan motifs of the blind arcades framing the lozenge-shaped openings. Bichromy also distinguishes the ferrules of the arches above the columns dividing the naves of the liturgical space and framing the apse, chapels and presbytery area. Similar to what was implemented in the Church of San Domenico Maggiore in Naples, shiny faux-marble stuccoes cover the columns, while the vaults of the aisles and transept are painted with blue backgrounds and gold stars. Colors and geometric motifs also characterize the intrados of the coffered ceiling and the glass surfaces, with the aim of restoring a uniform figurative and spatial unity and special light effects (Picone, 1996; Picone, 2000; Belli D'Elia and Derosa, 2018).

Fig. 5. Troia, Cathedral. Detail of the medieval polychrome decorations on the south-west elevation (photography by Maria Antonietta Catella).

3.2. *"Coloured Middle Ages" or "monochrome Middle Ages"? Sante Simone's restorations at Conversano Cathedral*

A few decades after Federico Travaglini's Apulian "embellishments", the use of polychromy, and in particular of two-colour banding reproposed with polished stucco imitating marble, is still appreciated, although a different idea of "Apulian Romanesque" begins to mature. The "Apulian Romanesque" is imagined as uniformly white and the region begins to seek its own cultural identity, independent of Neapolitan influence. The restorative events involving the Cathedral of Conversano between 1877 and the early 1880s (Guarnieri, 2007; Pollini, 2017) are emblematic of the different value attributed to color. In addition to Romualdo Moscioni's photographs (Fig. 6), these interventions are evidenced by the numerous images preserved in the Photo Library

Fig. 6. Conversano, the interior of the Cathedral in 1892. Photo: Kunsthistorisches Institut in Florenz – Max-Planck-Institut, photographer: Romualdo Moscioni.

of the Soprintendenza Archeologia, belle arti e paesaggio for the metropolitan city of Bari, which show the cathedral's state following the fire that occurred between 10 and 11 July 1911. In 1877, the Architect Sante Simone agreed to remove the Baroque decorations, adhering to the commission given to him by Bishop S. Silvestrin, who «wishing to give greater luster and decorum to the beautiful temple, proposed to cover it inside with polished plaster» (Simone and Sylos, 1896, p. 10). But with the continuation of the work and the discovery of the "Lombard-Pugliese" (Simone and Sylos, 1896, p. 10) features recurring in the various Cathedrals of Apulia, Sante Simone elaborates a new proposal for the implementation of «the way of true restoration» (Guarnieri, 2007, p. 47). It is no longer aimed at the polychrome decorations desired by the bishop, but at the rediscovery of «primitive architectural ornamentation» (Simone and Sylos, 1896, p. 10), elaborated on the basis of faint surviving traces. «Naked should remain the walls, as they were from the earliest times. They should all restore the walls in ashlar stone, make the deplorable fault caused by successive transformations disappear» (Simone and Sylos, 1896, p. 10). The disapproval of the project expressed in 1881 by the architects of the Ministry of Public Education and the criticism of Sante Simone's first interventions, which rendered an overly resigned image of the building, show that during the 1870s and 1880s the public was not yet fully ready to accept the image of the "Lombard-Pugliese", radically different from the "colored Middle Ages". These were the reasons that forced Sante Simone to please the patron. «Other works were carried out, but with criteria at all discordant from mine. With the only purpose of fulfilling the bishop's wish, [...] I agreed that the little columns of the three-mullioned windows of the women's gallery should be covered with cipolline stucco and the half-columns leaning against the pillars of the main nave should be executed in granite. The remainder of the church was to be plastered with glue, in the color of the limestone of the ancient masonry. While this covering was being executed, the crowd of the ignorant, who were ill-suited to see the temple restored to the simplicity of primitive Christian worship and stripped of chicanery, arose in protest. From the intimidated clamor, the good bishop ordered that the work be suspended, and the church be adorned with fictitious marbles and multicolored musaics: the people applauded, believing they could worship God exclusively in the orgy of colors and precious metals» (Simone and Sylos, 1896, p. 12).

In fact, the idea of a "monochrome Middle Ages" (Pollini, 2017), pursued by removing the plasterwork and leaving the walls of Apulia's main Romanesque monuments exposed in all their expressiveness, began to materialize with greater insistence from the last years of the 19th century. Took place the removal of the Baroque decorations of Bitonto Cathedral (Guarnieri, 2007; Belli D'Elia and Derosa, 2018) and of the superfetations and the «white stucco lining suspended inside the medieval three-ship building» (Belli D'Elia and Derosa, 2018, p. 264) of Bari Cathedral, built in 1737 by Domenico Antonio Vaccaro. Later, in the first half of the 20th century, the restorative tendency fully asserted itself with the demolition of the imitative coloured marble surfaces in the Cathedrals of Conversano (Guarnieri, 2007) and Trani (Belli D'Elia and Derosa, 2018). Not even Travaglini's "embellishment" of the Cathedral of Troia, removed between 1956 and 1959 in order to re-propose the presumed original medieval appearance of the building, is spared (Picone, 1996; Picone, 2000).

3.3. *Neo-medieval echoes in the minor architecture. The Church of San Giorgio Martire in Bari*

But the taste for the "colored Middle Ages" continued to persist in Apulia even in the early decades of the 20th century, manifesting some reverberations even in modernization operations of secondary and private religious buildings, as evidenced by the rural Church of San Giorgio Martire in Bari. In 1920, the small 11th-century church, which had become the aristocratic chapel of the adjacent 19th-century farmhouse, underwent significant transformations. These interventions were promoted and financed by the Sarnelli family, owners of the church, probably with the aim of reinventing the building in a new neo-Romanesque appearance. Again, color is the protagonist of the interior space: along the wall faces, up to the impost of the vaults, it is shown in alternating horizontal bands of white and blue plaster simulating marble. The pattern of vertical lines on the two-coloured bands renders the fake isodomic device of the marble cladding, which in reality hides the less regular masonry, highlighted by the partial fall of the plaster. Thus, no proportional and formal relationship seems to emerge between the stone elements constituting the wall and the fictitious ones of the cladding. The invention and imitation of neo-Romanesque characters overlap and blend with the pre-existing. On the other hand, the white plasters covering the arches, vaults and the wall portions above the shutters are different: the horizontal incisions that divide the covering into bands and those made at the plasters covering the arches' ferrules seem to coincide with some of the real joints of the wall faces below. In addition, the reproduction in stucco along the intradossal surfaces of the vaults and arches of plastic decorative elements peculiar to Apulian medieval lithic architecture - such as checkerboard cornices, cruciform lobes framing palmettes and dentils - gives a greater neo-Romanesque character to the rural church (Derosa and Triggiani, 2005).

Following prolonged neglect and a fire in 2014, the polychrome surfaces of the church were severely damaged and almost totally destroyed. Curtain walls at the doors currently do not allow access to the building, emblematic of neo-medievalism in Apulia.

3.4. *The independence of colour: decorative experiments in 20th century churches*

But the fictitious polychromatic vestments found the greatest freedom of expression in the new creations of neo-Gothic and neo-Romanesque churches in Apulia. The decorative aspects become completely independent of the architectural structures, realised with new materials and construction techniques, and the surfaces become vast areas for experimentation with the most diverse decorative motifs. In Bari, neo-medieval dictates asserted themselves between 1900 and 1930 in conjunction with urban expansion and the establishment of new parishes. They manifest themselves with chromatic and decorative peculiarities in the Churches of the Immacolata (Fig. 7) and San Giuseppe (Fig. 8) designed by Engineer Mauro Amoruso-Manzari.

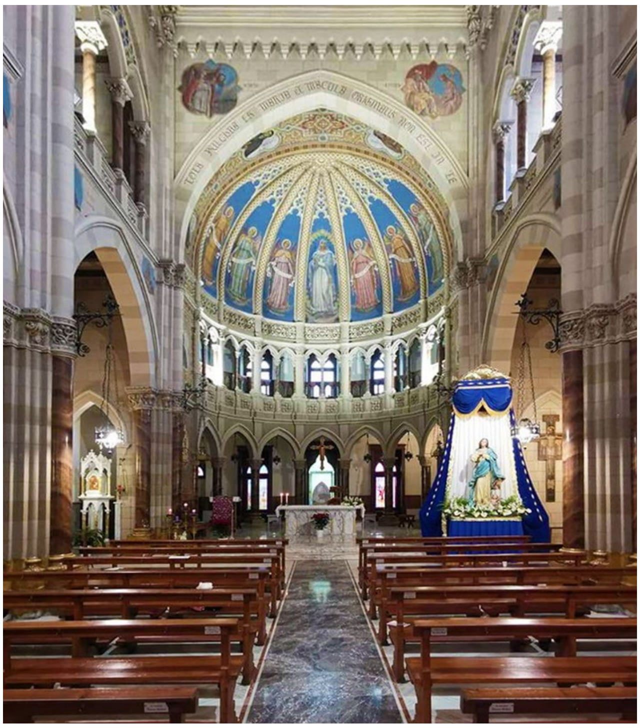


Fig. 7. Bari, Church of the Immacolata Concezione. Current state of conservation (photography by Maria Antonietta Catella).

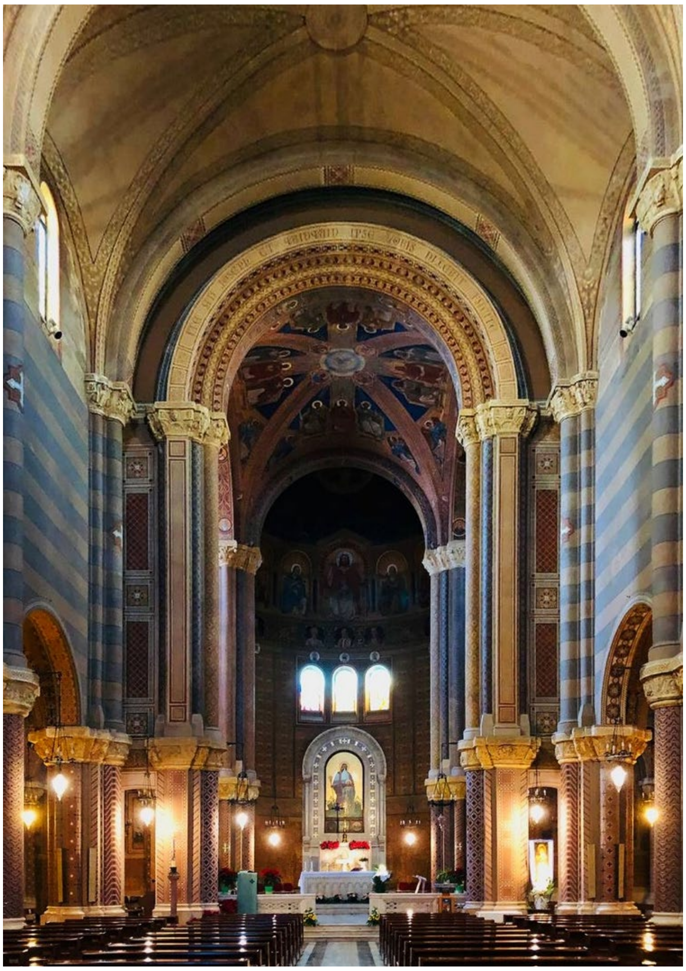


Fig. 8. Bari, Church of San Giuseppe. Current state of conservation (photography by Maria Antonietta Catella).

In the first church, built between 1923 and 1926 and consecrated in 1936, the Artist Mario Prayer enhances the presbytery area with elaborate polychrome decorations, while the surfaces of the rest of the rooms take on an illusionistic character. They are marked by imitative paintings of isodomic wall facings and the lintels of the ogival arches, composed of white, grey, beige and brown "ashlars".

In contrast, in the Church of San Giuseppe, built between 1913 and 1930, Mario Prayer experiments with plural and articulated polychrome painted decorations on the facings of the presbyterial, apse and the masonry of the area, on the columns, on the intradoses of the arches and on the areas adjacent to the ribs of the vaulted structures. They are emergent from the horizontal scans in white and blue bichrome bands painted on the facings and half-columns of the upper order of the nave, above the columns separating the spaces of the liturgical environment.

A similar chromatic device also distinguishes the interior surfaces of the Salesian Church of Sacro Cuore in Brindisi (Fig. 9), designed by Architect Giulio Valotti between 1931 and 1934. In the latter two examples, the two-tone colour scheme seems to evoke the chromatic peculiarities of neo-medieval architecture, but without any imitative intent of the masonry: the horizontal two-tone bands have no vertical interruptions along the surfaces. There are no ferrules at the arches above the columns or at thewindows. In this way, is realized the total independence of the decorations from the structural logic of the buildings.

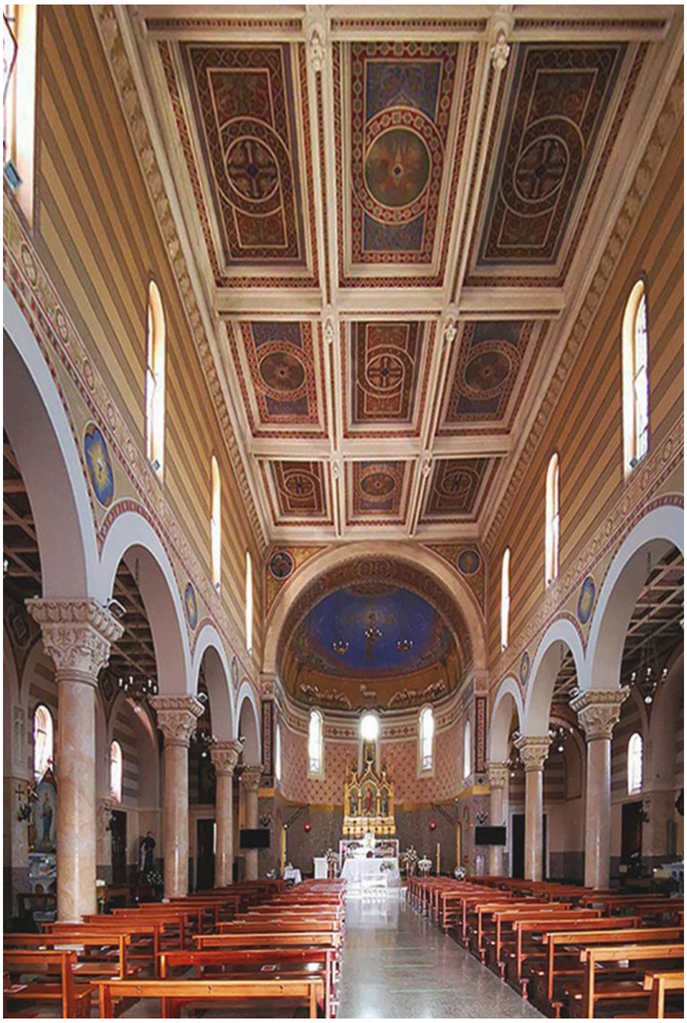


Fig. 9. Brindisi, Church of Sacro Cuore. Current state of conservation (photography by Maria Antonietta Catella).

4. Conclusion

This paper briefly illustrates the first results of an ongoing research project aimed at investigating the significance attributed to the colour of architecture during the 19th and 20th century in view of the definition of national identity. By analysing the restoration theories expounded by the protagonists of the time, the operational choices made in Italy and other European countries in the restoration of medieval monuments and in neo-Romanesque and neo-Gothic realisations, it is possible to understand how the colour of architecture was perceived at the time. Today's way of looking at medieval art has been filtered and determined by the taste of the 19th and early 20th century.

Furthermore, the in-depth study of case studies in Apulia contributes to analysing the extent of the spread of neo-medieval taste in the region, providing useful insights into a strand of expression that is still not fully investigated today.

The study of the polychromatic neo-medieval surfaces of the monuments in Apulia was carried out thanks to the inspections carried out at the buildings under study, the consultation of the publications produced so far and the documentation held at the archives in the region - such as the State Archives in Bari and the Archives of the Soprintendenza Archeologia, belle arti e paesaggio for the metropolitan city of Bari -. Also important was the observation of historical photographs of the monuments, stored at the Photo Library of the Kunsthistorisches Institut in Florenz - Max-Planck-Institut and the Photo Library of the Soprintendenza Archeologia, belle arti e paesaggio per la città metropolitana di Bari. The contextual study of buildings that showed polychrome surfaces in the past and those that continue to show polychrome surfaces created between the 19th and 20th centuries currently provides an insight into a true historical phenomenon of great importance for the definition of regional and national identity. Due to their historical, artistic and identity values, the polychrome surfaces of Apulia's monuments need to be preserved and undergo constant maintenance or restoration. This can be said because the rediscovery of the "Apulian Romanesque" did not only take place with the well-known restorations carried out between the 19th and 20th century - consisting of the demolition of Baroque decorations and the restoration of a presumed original configuration - but also with the realisation of neo-medieval polychrome surfaces. At present, the historical, artistic and intangible importance of the latter is little known, as the recent events of abandonment and destruction of the Church of San Giorgio Martire in Bari testify. This is why it is necessary to get to know and enhance the cultural significance of Apulia's polychrome mediaeval surfaces. It is necessary to do this with a view to their conservation and constant maintenance, which is currently carried out regularly on the restorations implemented in the region between the 19th and 20th centuries.

5. Conflict of interest declaration

The author declares no conflict of interest related to this publication.

6. Funding source declaration

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sector.

7. Short biography of the author

Maria Antonietta Catella is an Architect, Specialist in Architectural and Landscape Heritage and PhD. She undertakes studies and research pertaining to knowledge, theories of restoration, protection and conservation of architectural heritage and the historic city, participating in national and international conferences, seminars, advanced training courses, workshops and internships relevant to the aforementioned topics.

Licensing terms

References

Belli D'Elia, P. e Derosa, L. (2018) 'L'invenzione del Romanico pugliese: riscoperte, restauri, ripristini dal XVII secolo agli anni Venti del Novecento', *Arte medievale*, 8 (4), pp. 261–276.

Billi, E. (2014) 'Cercando l'«incanto fantastico di colorito»: restauri italiani di monumenti medievali nel XIX secolo', *BTA Bollettino Telematico dell'Arte*, 737, pp. 1–12. http://www.bta.it/txt/a0/07/bta00737.html

Blanchard, J. (1991) 'Il "revival" delle strisce: episodi di gusto architettonico da Street a Stirling', in Lamberini, D. (ed.) *Il Bianco e il Verde. Architettura policroma fra storia e restauro.* Firenze: Alinea Editore, pp. 53–64.

Chatterjee, A. (2017). Between colour and pattern: Ruskin's ambivalent theory of constructional polychromy, *Interstices: Journal of Architecture and Related Arts,* 18 (18), pp. 11–24. https://doi.org/10.24135/ijara.v0i0.4

Civita, M. (1995) 'Il contributo di Federico Travaglini e di Corrado de Judicibus ai restauri ottocenteschi della cattedrale di Altamura', Altamura, 36, pp. 301–335.

Derosa, L. e Triggiani, M. (2005) 'S. Giorgio Martire: un esempio di chiesa rurale alle porte di Bari', *Studi Bitontini*, 80, pp. 5–26.

Fachechi, G.M. (2014) 'Quando le cattedrali non erano bianche: uso e funzione del colore nell'architettura sacra medievale', in Zammerini, M. (ed.) *Il mito del bianco in architettura.* Macerata: Quodlibet, pp. 85–113.

Fachechi, G.M. (2016) 'Senso del colore e assenza di colori nell'architettura sacra medievale e nelle sue 'rivisitazioni' in Italia: qualche considerazione sulla facies esterna', *Opus Incertum*, 2, pp. 18–33. doi: https://doi.org/10.13128/opus-19680.

Guarnieri, A. (2007) *Pietre di Puglia. Il restauro del patrimonio architettonico in Terra di Bari tra Ottocento e Novecento.* Roma: Gangemi Editore, p. 13, pp. 46–49, pp. 69–73, pp. 87–100, pp. 133–134.

House, J.P.H. (1963) 'The Architecture of William Butterfield (1814-1900)', *Transactions of the Ancient Monuments Society,* 2, pp.109–130.

Jackson, N. (2004) 'Clarity or Camouflage? The Development of Constructional Polychromy in the 1850s and Early 1860s', *Architectural History,* 47, pp. 201–226.http://dx.doi.org/10.1017/S0066622X00001751

Mangone, F. (2015) 'Neorinascimento e «stile nazionale» nell'Italia unita, tra teoria e prassi', in Brucculeri, A. e Frommel, S. (eds.) *Renaissance italienne et architecture au XIX e siècle Interprétations et restitutions.* Roma: Campisano Editore, pp. 273–282.

Mangone, F. (2018) 'Prefazione', in Savorra, M., Questioni di facciata. *Il "completamento" delle chiese in Italia e la dimensione politica dell'architettura 1861-1905*. Milano: Franco Angeli, pp. 9–10.

Neri, M.L. (1997) 'Stile nazionale e identità regionali nell'architettura dell'Italia post-unitaria', in Bertelli, S. (ed*.) La Chioma della Vittoria. Scritti sull'identità degli italiani dall'Unità alla seconda Repubblica.* Firenze: Ponte alle Grazie, pp. 133–169.

Paine, A. (2011) Façades and stripes: An account of striped façades from medieval Italian churches to the architecture of Mario Botta. Society of Architectural Historians, Australia and New Zealand (SAHANZ) Annual Conference, Brisbane, QLD, Australia, 7-10 July 2011. Available at: chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.phab.com.au/wp-content/uploads/2013/02/Paine-Ashley-SAHANZ-2011.pdf (Accessed: 10 October 2024)

Picone, R. (1996) *Federico Travaglini. Il restauro tra 'abbellimento' e ripristino.* Napoli: Electa Napoli, p. 59, p. 60, pp. 65–87, pp. 90–101, pp. 107–116.

Picone, R. (2000) '"Ristauro" e de-restauro. Il caso della Cattedrale di Troia in Puglia', in Casiello, S. (ed.) *Restauro dalla teoria alla prassi*. Napoli: Electa Napoli, pp. 76–101.

Pollini, G. (2017) 'Restauro, ripristino e invenzione della policromia pittorica nell'architettura medievale. Alcuni esempi tra Napoli e Puglia nel XIX secolo', in NUME (ed.) *3° Ciclo di Studi Medievali. Atti del Convegno (Firenze, 8-10 settembre 2017).* Lesmo: Etabeta Ps, pp. 443–457.

Romeo, E. (2013) 'Memoria e percezione dell'antico in Viollet-le-Duc, dagli studi di Roberto di Stefano alla lettura di documenti inediti', in Aveta, A., Di Stefano, M. (eds.) *Roberto Di Stefano: un protagonista nello sviluppo del restauro e della conservazione.* Napoli: Arte Tipografica Editrice, pp. 159–164.

Savorra, M. (2005) 'Il Medioevo e la Sicilia. Disegni e itinerari formativi dei *pensionnaires* francesi nel XIX secolo', *Lexicon. Storie e architettura in Sicilia*, 2, pp. 24–32.

Savorra, M. (2018) *Questioni di facciata. Il "completamento" delle chiese in Italia e la dimensione politica dell'architettura 1861-1905.* Milano: Franco Angeli, pp. 11–14, p. 16.

Selvafolta, O. (2007) 'Il Cimitero Monumentale, il Famedio e la città di Milano', in Giuffrè, M. *et al. (eds.) L'architettura della memoria in Italia. Cimiteri, monumenti e città 1750-1939.* Milano: Skira, pp. 183–199.

Simone, S. e Sylos, L. (1896) *Il Duomo di Conversano*. Trani: V. Vecchi, p. 10, p. 12.

Street, G.E. (1855) *Brick and Marble in the Middle Ages:* Notes of Tours in the North of Italy. London: J. Murray, p. 282.

Varagnoli, C. (2017) 'Sense and sensibility. Viollet-le-Duc e l'Italia', *Conversaciones… con Eugène Viollet -le-Duc y Prosper Merimée*, 3, pp. 113–124.

Zucconi, G. (1997) *L'invenzione del passato. Camillo Boito e l'architettura neomedievale.* Venezia: Marsilio, p. 20, p. 23, p. 27, p. 29, p. 36.

Zucconi, G. (2016) 'I medievalisti Pietro Selvatico e Camillo Boito, tra Padova e Venezia', *Archeologia dell'Architettura*, 21, pp. 11–16.

Chromatic Image: a New Imaging Method for the Examination of Works of Art

Camilla Perondi

Art + Image, Copenhagen, Denmark, camilla@artplusimg.com

Corresponding author: Camilla Perondi (camilla@artplusimg.com)

ABSTRACT

This study introduces a cost-effective and accessible tool, the chromatic image, specifically designed to amplify the visual features of an image during the preliminary stages of the analysis of an art object. The chromatic image enhances the visualization of subtle hues often unnoticeable in traditional colour images. The method involves processing a high-resolution colour image using its chromatic channels (a* and b*) from the CIE Lab colour space. This creates a new image that highlights variations in hues independent of tonal values. This initial research investigates the application of the chromatic image on easel paintings and works on paper. Results demonstrate the technique's effectiveness in revealing details in shadowed areas, enhancing the readability of red chalk drawings, and potentially aiding in damage detection. The method also holds promise for studying brushwork and areas reworked by the artist. This new tool offers a valuable and accessible addition to the toolkits of art historians, scientists, and conservators alike, paving the way for further investigation using more advanced techniques.

KEYWORDS technical imaging, chromatic image, image processing, preliminary examination, forensic imaging

RECEIVED 14/08/2024; **REVISED** 18/10/2024; **ACCEPTED** 02/11/2024

1. Introduction

Being able to discern an artwork's attributes is very important for every professional in the cultural field. Whether these visual attributes are associated with its aesthetic features (Cubero, 2010), the creative process of its making (Fowler, 2019), or any form of change in structural or aesthetic function (Strlič *et al.*, 2013), the specialist is called to identify and address them.

In heritage science, when such attributes ignite enough curiosity, a research process is pursued to answer queries. Visual inspection remains a fundamental, first approach to identify surface characteristics and potential alterations on the work of art. However, these observations are highly dependent both on one's individual experience and the limits of the human visual system. For this reason, an analytical protocol is usually defined, starting from preliminary techniques – like multiband imaging and XRF analyses – to more selective methods chosen on the basis of the specific research queries.

Among the technical imaging techniques, often included at the preliminary stages of a research inquiry, false-colour composites are a regarded solution for the interpretation of complex data, as they allow to highlight specific features in a scene, visualise information beyond human vision, and enhance the contrast between features. In most cases, false-colour imagery involves the combination of two or three images, of which some carry spectral information outside of the visible range, like NIR or SWIR datasets (Daffara and Fontana, 2011; Legnaioli *et al.*, 2013; Pronti *et al.*, 2019). Yet, the collection of spectral data already falls within the boundaries of an analytical protocol, as it requires specialised training and equipment. Such limit poses accessibility concerns, as readily available methods often serve as the first line of investigation for researchers in smaller institutions and independent professionals (von Saint-George and Lewerentz, 2008; Jaskierny, 2021; Nehring, Girard and Rabin, 2024).

The study presented here aims to introduce the chromatic image, a new visual tool for the examination of works of art at the earliest stage of research without the need for moving the objects from display or storage. The method represents a novel approach to image editing grounded in empirical observation and experimentation, rather than relying on mathematical models. Nonetheless, this new false-colour technique expands the capabilities of visible colour imaging, enabling a swift and informative initial assessment accessible to historians, conservators, and scientists alike.

2. Method

The basic principle behind chromatic imaging involves creating a colour-coded composite image of the chromatic channels (*a** and *b**) of the Lab colour space to enhance subtle differences in hues within a scene. A conventional colour image and an image editing software are required to process a chromatic image. For this study, the author sourced full-resolution TIFF files from the online collection of the Cleveland Museum of Art, which are available for the works of art classified as of public domain. A total of forty-two images of easel paintings, mural paintings, watercolours, prints, and drawings spanning through different ages have been included in the study. Thirty images had colour encoding sRGB 8-bit, while the remaining twelve were encoded in an AdobeRGB 8-bit colour space.

Adobe Photoshop® was used to process the dataset into chromatic images. The choice of this software was driven by its widespread familiarity to photographers, imaging specialists, and conservators who occupy a forefront position in the forensic documentation of artworks in institutions and independent laboratories. While the use of proprietary software limits transparency in the process, its extensive features and capabilities made it a suitable choice for this initial exploration. Future studies could investigate the replicability of the workflow by using other, open-access tools like GIMP, ImageJ, or Python libraries for chromatic image creation. The step-by-step process followed for this study is detailed in Section 2.1 of this article, and a link to a permanent downloadable Adobe Photoshop® droplet is found in Section 5.

When an image is converted from RGB to Lab, the colours in each pixel are described with three coordinates: black opposed to white (*L** or lightness) for the reproduction of the tonal values, green opposed to red (*a**) and blue opposed to yellow (*b**) for the reproduction of the hues. In image editing software, individual channels are visually rendered as a grayscale map of the intensity values for each *L**, *a*,* and *b** coordinate. Low values of lightness are represented as dark (pixel values close to zero), while highlights have higher values (pixel values close to 255). In turn, pixels in the channels *a** and *b** can assume positive and negative values, typically between -128 and 127. Negative values for *a** and *b** are represented as darker, while positive values as highlights. Consequently, positive values of *a** (red) and of *b** (yellow) are represented with higher pixel values (> 0); conversely, negative values of *a** (green) and *b** (blue) are rendered with lower pixel values (< 0).

The starting colour image was converted from RGB to Lab, obtaining the three channels *L**, *a*,* and *b**. The lightness channel *L** was unaccounted for from here on. Adobe Photoshop® does not allow to work with two-channel images, requiring the handling of the two channels *a** and *b** as greyscale images in themselves, which can then be layered and blended together in a non-destructive way within a three-channel colour space. The 'Screen' blending mode on Adobe Photoshop® was chosen as it consists into a multiplication of the inverse of the blend and base pixel values (Adobe, 2024); in other words, higher pixel values are favoured against lower ones. The effect is similar to projecting multiple photographic slides on top of each other.

A monochrome colour filter was assigned to each chromatic channel. This way, the positive pixel values (corresponding to red for *a** channel and yellow for *b** channel) were rendered with a more saturated hue than the negative pixel ones. The colour coding of each layer was obtained by adding a 'Solid color' adjustment layer (blue for *b** and yellow for *a**) blended to their respective chromatic layers via 'Color burn' blending mode. This blending mode was favoured as it increases the contrast between the base and the blend colour while preserving the luminosity values (Adobe, 2024). The choice of colours to attribute to the *a** and *b** channels was based on the efficacy of the simultaneous contrast derived by the blue-yellow opposition, which results in a higher perception of the details in the scene (Rabin, 2004; Berns, 2016, p. 43).

A final 'Levels' non-destructive adjustment layer was added to adjust the overall tonal range of the chromatic image. Since the intensity values of *a** and *b** can vary considerably from image to image, the tonal range can be optimised by choosing the correction option 'Enhance Per Channel Contrast' (Adobe, 2023). At this stage, the histogram is stretched to cover the entire range of tones, on one side contributing to a stronger contrast between the hues, and leading to the formation of artifacts due to a more or less severe quantisation of the levels.

The resulting project included five layers: a 'Levels' adjustment layer and two 'Solid color' adjustment layers clipped to the layers of the two channels. The sequence of actions ensured a non-destructive approach towards the original values of *a** and *b**. The images were then saved locally as uncompressed TIFF files inclusive of the layers. All the actions were recorded in a macro to run the process automatically at every new image of the dataset and secure repeatability and consistency of the workflow.

It is known that Adobe Photoshop®'s ICC Profile Connection Space (PCS), used in the colour mode conversions, operates with the D50 white reference point (Plaisted, 2011). Other software and coding image libraries may rely on a different standard illuminant (most commonly D65) for the conversion RGB-to-Lab. Given the proprietary nature of Photoshop®'s algorithms, it was not possible to assess what other variables in the RGB-to-Lab conversion may differ from the ones used in other software. No tests were performed to determine the resulting chromatic images in different scenarios than the one presented here.

2.1 *Step-by-step process*

The step-by-step process used for this study is detailed as follows:

1. Convert the colour mode from RGB to Lab
2. From the 'Channels' tab:
   a. Select a* channel
   b. Select all (Ctrl + A)
   c. Copy (Ctrl + C)
   d. Select Lab
3. From the 'Layers' tab:
   a. Paste (Ctrl + V)
4. Rename the new layer as 'a*', untoggle view and select 'Background' layer
5. Repeat point 2 and 3 for the b* channel
6. Delete 'Background' layer
7. Convert the colour mode from Lab to RGB (don't merge layers)
8. Add a 'Solid color' adjustment layer above b*
   a. Assign blue (0, 0, 255)
   b. Assign 'Color burn' blending mode
   c. Create clipping mask (Alt + Ctrl + G)
9. Select a*, toggle view, and assign 'Screen' blending mode
10. Repeat point 8 for a* layer
    a. Assign yellow (255, 255, 0) to the 'Solid color' adjustment layer
11. On top of the existing layers, add a 'Levels' adjustment layer
    a. Set auto correction options to 'Enhance Per Channel Contrast'

3. Results

3.1 *First interpretations and examples*

While colours can be described with three coordinates in the Lab colour mode (lightness and two chromatic axes), the chromatic image exploits only the two chromatic values *a** and *b**. As a result, the final image is a false-colour, spatially resolved map of hues which are present in the starting colour image. It visually describes differences in hues and saturation regardless of their original tonal values. It was observed that the most effective way to interpret chromatic images involved viewing them beside the original image for direct comparison.

As illustrated in Figure 1, the chromatic image is particularly effective in discriminating reds against yellows and greens against blues. A practical example can be found in the watercolour by Honoré Daumier *The Art Lovers* (Figure 2). The chromatic image shows that the small, tinted frame on the right appears to be painted with an orange shade all around then reinforced with a redder wash along the left side. While it does not provide any notion on the pigments' composition, the chromatic image reveals clear insights on the extension of the red passages in contrast to the yellow ones.

All the luminosity values of the starting image are eventually suppressed into a medium grey. Artworks with predominantly neutral tones tend to look flat and lack vibrancy in their chromatic images (Figure 2). This effect is also observed in areas where the artist intentionally left a white background exposed, with the information almost entirely lost in the chromatic image. Additionally, using the method presented here on paintings with thick impasto results in a loss of surface texture in the final rendering (Figure 3). While some may view this as a drawback, it is important to note that the chromatic image emphasizes chromatic information just like other computational imaging methods – like structured light scanning – focus on morphological characteristics alone making these techniques complementary.

The digital suppression of the surface texture may instead play a role in the study of the brushwork and how the paint was applied, as is the case for the highlighted marbling effect of the wet-on-wet passages in Van Gogh's *Two Poplars in the Alpilles near Saint-Rémy*.

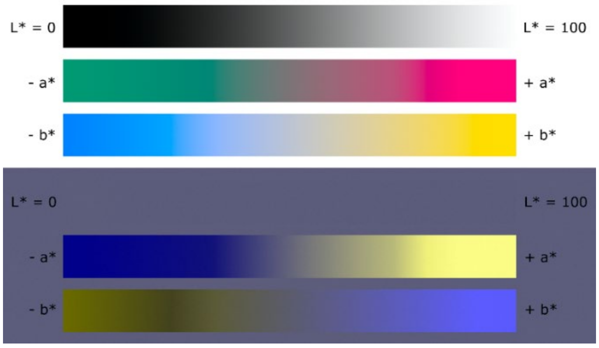


Figure 1. Gradient illustration of the L, a and b channels and their rendering in the chromatic image with adjusted layers value.

Figure 2. Honoré Daumier, Art Lovers, c. 1863. The Cleveland Museum of Art, inv. 1927.208. Left: detail in diffused light; right: same detail in the chromatic image.

Figure 3. Vincent van Gogh, Two Poplars in the Alpilles near Saint-Rémy, 1889. The Cleveland Museum of Art, inv. 1958.32. Left: detail in diffused light; right: same detail in the chromatic image.

The most frequently successful application of the chromatic image was found to be the heightening of shadowed areas, which often emerged with a higher degree of detail than in the starting colour image. The effect seems to stem from the combination of the suppression of the lightness channel – which brings all tonal values to a medium grey – and the simultaneous contrast of the blue-opposed-to-yellow colour scheme. The chromatic images of some particularly dark paintings, like Jan Steen's *Esther, Ahasuerus, and Haman* (Figure 4), reveal the capacity of this technique to enhance the detailing of the architectural features in the background.

A specific case study is the application of the chromatic image for the enhanced reading of red chalk drawings. While any graphite or black chalk underdrawing – as well as white washes and highlights – may get lost in the process, the red chalk marks become remarkably more evident and detailed thanks to the ability of the method to discriminate yellow from red hues. In this specific use case, the chromatic image may acquire an "inverted colour scheme", similar to a radiograph, where yellow represents the red chalk marks and the blue is associated with the light orange tint of the aged support (Figure 5). An inversion of the colour scheme may allow for a more convenient reading.

Figure 4. Jan Steen, Esther, Ahasuerus, and Haman, c. 1668. The Cleveland Museum of Art, inv. 1964.153. Top: detail in diffused light; bottom same detail in the chromatic image.

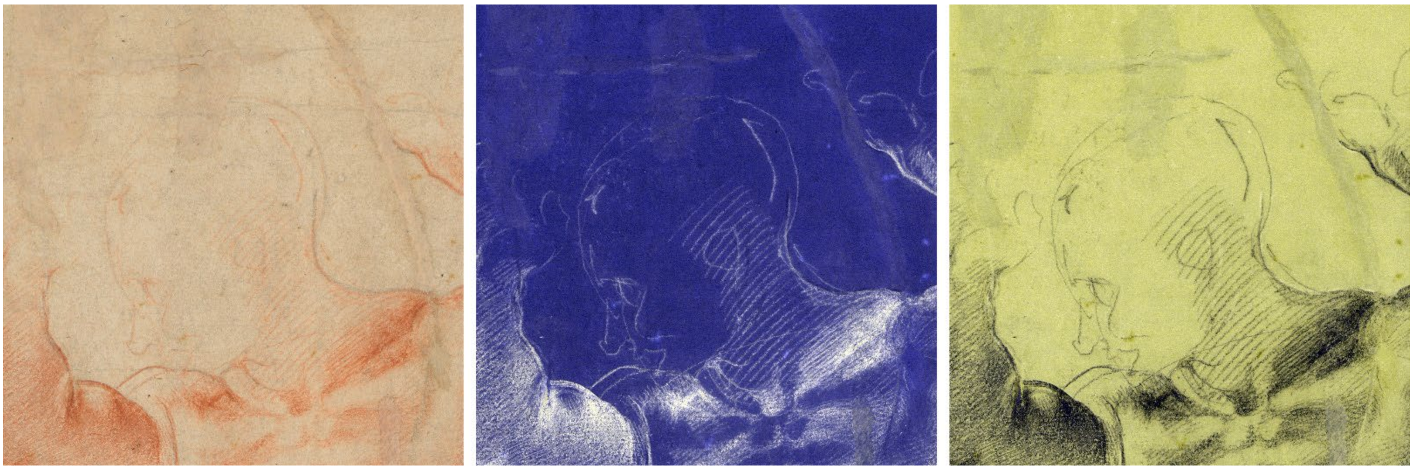


Figure 5. Michelangelo Buonarroti, Study for the Nude Youth over the Prophet Daniel (recto), 1510–11. The Cleveland Museum of Art, inv. 1940.465. Left: detail in diffused light; centre: same detail in the chromatic image; right: chromatic image with colour inversion applied.

 DOI: 10.23738/CCSJ.160205

In some instances, the chromatic image provided insights on localised damages, especially paint losses and abrasions of the paint film not readily disclosed in diffused light. Its application on works on paper resulted particularly effective in documenting the extension of stains, foxing, and acidic corrosion inherent to the iron-gall ink medium, as seen in the drawing by Fra Bartolomeo in Figure 6. The utility of the chromatic image to monitor deterioration patterns should be investigated with further studies, especially in the context of existing methodologies (Kim *et al.*, 2019). While this new tool can detect various damages affecting the colours of an object's surface, it was not considered reliable in the identification of existing paint retouches – a task better suited for UV-induced luminescence imaging (Webb, 2019).

In a handful of cases, within the relatively small group of artworks processed in this study, the chromatic image highlighted areas of overpaint associated with pentimenti or reworks, as is the case for the foliage in Henri Rousseau's *Fight between a Tiger and a Buffalo* (Figure 7). One should note that chromatic images lack the ability to penetrate objects like infrared or X-ray imaging and that they are limited to highlighting existing details that might be subtle or difficult to see with the naked eye. In this instance, the power of the chromatic image may rely on the suppression of visual noise in complex colour schemes while increasing the contrast between analogous colours.

Figure 6. Fra Bartolomeo, Farmhouse on the Slope of a Hill, c. 1508. The Cleveland Museum of Art, inv. 1957.498. Left: detail in diffused light; right: same detail in the chromatic image.

Figure 7. Henri Rousseau, Fight between a Tiger and a Buffalo, c. 1908. The Cleveland Museum of Art, inv. 1949.186. Left: detail in diffused light; right: same detail in the chromatic image.

3.2 *A note on image quality*

The best outcomes were achieved with an uncompressed TIFF or PNG file as the starting colour image. The lossy compression of the JPEG format resulted particularly evident in the form of its characteristic compression pattern that hampered the overall interpretation. Additionally, the removal of the *L** channel reduces considerably the distinction of details, as it is the channel bearing such information in the Lab colour space (Berns, 2016, pp. 50–68). Starting with an adequate spatial resolution, enough to distinguish small features present on the work of art, represents an advantage.

In order to obtain a faithful separation of hues and ensure replicability of the method, the object should ideally be captured according to established studio photography best practices (Frey *et al.*, 2011; Farnand, 2017) and the image appropriately colour managed using a scene-referred colour chart, where measured values should be preferred against numinal ones (Olejnik-Krugly and Korytkowski, 2020; International Organization for Standardization, 2021; Kirchner *et al.*, 2021). This study did not assess how different colour encodings may affect the final rendering of chromatic images, although a larger gamut found in colour spaces like ProPhotoRGB and eciRGBv2 might result into a more efficient hue separation in images rich in colour fields with subtle gradients.

4. Discussion

As a new visualisation tool with reduced implementation costs, the chromatic image could be readily included in the preliminary stages of any technical or art-historical investigation workflow. During this study, the method offered several new ways of observing works of art. It does not provide any insights on the pigments composition, yet it shows potential in support to the decision making of analytical plans and aid the selection of representative samples. Its applications for supporting conservation endeavours should also be considered, especially as an aid for the location and mapping of areas of damage also on large and monumental surfaces. The use of the chromatic image in the study of drawings and manuscripts is encouraged, especially where partial fading or support discolouration present the necessity to enhance the contrast of the desired marks. This new imaging method may also foster the study of brush marks and paint applications that characterise an artist's working method, as well as bring to light strongly shadowed areas in low-key compositions. Finally, the chromatic image may offer a chance to inspect artworks for potential reworks and overpaints, further characterising the artist's creative process.

A compelling aspect of the applications of the technique presented here is its contained cost, since it does not require specialized equipment aside from the tools of a conventional photographic studio and a robust colour management pipeline, like the one suggested by the American Institute for Conservation (Frey *et al.*, 2011). And while the study presented here relied on the use of a commercial software, a workflow based on freeware, open source software could be investigated in the future, cutting down the costs and increasing further the accessibility of the method.

One of the inherent limitations of chromatic images is the possibility of encountering situations where there simply is no significant feature to be seen – or rather, none of the aforementioned characteristics is highlighted. However, the lack of results should not elude from the notion that more advanced imaging techniques could be more appropriate for the investigation of the object. In fact, chromatic images do not have any penetrative properties, as spectral imaging and radiography do, nor can provide compositional information. Another major limitation could be encountered in case of paintings coated by a heavily oxidised varnish; here, the yellow component may considerably shift the overall signals towards positive values of the *a** channel, masking potentially relevant features coming from other hues. The thresholds of these limits should be investigated in future studies.

Overall, the full potential of the chromatic image is yet to be fully explored, also in the perspective of using other software and image processing libraries that would amplify its accessibility to those institutions and professionals that make large use of open-source tools. For this reason, the author invites researchers in museums and independent laboratories to share their experiences with the author in their use of this new imaging tool.

5. Supplementary materials

A downloadable Adobe Photoshop® droplet for Windows is openly and permanently available on Figshare under licence CC-BY 4.0 at the following address: https://doi.org/10.6084/m9.figshare.26250494.

6. Data availability

The images presented in this study were derived from open source resources available in the online collection of The Cleveland Museum of Art at: https://www.clevelandart.org/art/collection/search?rights=1.

7. Conflict of interest declaration

The author declares no conflicts of interest.

8. Funding source declaration

This research received no external funding.

9. Acknowledgment

I am indebted to Kurt Heumiller, photographer and 3D Program Coordinator at the National Gallery of Art, Washington D.C., for his guidance.

10. Short author biography

Camilla Perondi - MSc in Science for the Conservation of Cultural Heritage (2014) from the University of Bologna. She is Director and Imaging Specialist at Art + Image, a private practice based in Copenhagen, Denmark. Her work focuses on the use of imaging methods for the examination of cultural artifacts.

References

Adobe (2023) *Photoshop User Guide: Make quick tonal adjustments*. Available at: https://helpx.adobe.com/content/help/en/photoshop/using/making-quick-tonal-adjustments.html (Accessed: 19 June 2024).

Adobe (2024) *Photoshop User Guide: Blending modes*. Available at: https://helpx.adobe.com/content/help/en/photoshop/using/blending-modes.html (Accessed: 26 May 2024).

Berns, R.S. (2016) *Color Science and the Visual Arts: A Guide for Conservators, Curators, and the Curious*. Getty Publications.

Cubero, A.V. (2010) ‘Una aproximación metodológica en el análisis de las obras de arte’.

Daffara, C. and Fontana, R. (2011) ‘Multispectral infrared reflectography to differentiate features in paintings’, *Microscopy and Microanalysis*, 17(5), pp. 691–695. Available at: https://doi.org/10.1017/S1431927611000031.

Farnand, S.P. (2017) ‘Evaluating Perceived Capture Quality for the Digitization of Cultural Heritage Objects’, *Archiving Conference*, 14(1), pp. 88–92. Available at: https://doi.org/10.2352/issn.2168-3204.2017.1.0.88.

Fowler, C. (2019) ‘Technical Art History as Method’, *The Art Bulletin*, 101(4), pp. 8–17. Available at: https://doi.org/10.1080/00043079.2019.1602446.

Frey, F. *et al.* (2011) *The AIC Guide to Digital Photography and Conservation Documentation*. Edited by J. Warda.

International Organization for Standardization (2021) ‘ISO 19264-1:2021 Photography — Archiving systems — Imaging systems quality analysis — Part 1: Reflective originals’.

Jaskierny, D.M. (2021) ‘Technical entry of Jean Siméon Chardin, “Still Life with Cat and Fish”, 1728’, in A.M. DeGalan (ed.) *French Paintings and Pastels, 1600-1945: The Collections of the Nelson-Atkins Museum of Art*. Kansas City: The Nelson-Atkins Museum of Art. Available at: https://doi.org/10.37764/78973.5.310.

Kim, G. *et al.* (2019) ‘Image-Based Quantitative Analysis of Foxing Stains on Old Printed Paper Documents’, *Heritage*, 2(3), pp. 2665–2677. Available at: https://doi.org/10.3390/heritage2030164.

Kirchner, E. *et al.* (2021) ‘Exploring the limits of color accuracy in technical photography’, *Heritage Science*, 9(1), p. 57. Available at: https://doi.org/10.1186/s40494-021-00536-x.

Legnaioli, S. *et al.* (2013) ‘Recovery of archaeological wall paintings using novel multispectral imaging approaches’, *Heritage Science*, 1(1), p. 33. Available at: https://doi.org/10.1186/2050-7445-1-33.

Nehring, G., Girard, S. and Rabin, I. (2024) ‘Conservation and Technical Evaluation of an Early Medieval Papyrus Codex’, *Studies in Conservation*, 69(2), pp. 77–87. Available at: https://doi.org/10.1080/00393630.2023.2183554.

Olejnik-Krugly, A. and Korytkowski, P. (2020) ‘Precise color capture using custom color targets’, *Color Research & Application*, 45(1), pp. 40–48. Available at: https://doi.org/10.1002/col.22435.

Plaisted, P. (2011) ‘The Reference White in Adobe Photoshop Lab Mode’, *Color-Image.com*, 29 October. Available at: https://color-image.com/2011/10/the-reference-white-in-adobe-photoshop-lab-mode/ (Accessed: 15 April 2024).

Pronti, L. *et al.* (2019) ‘Post-Processing of VIS, NIR, and SWIR Multispectral Images of Paintings. New Discovery on the The Drunkenness of Noah, Painted by Andrea Sacchi, Stored at Palazzo Chigi (Ariccia, Rome)’, *Heritage*, 2(3), pp. 2275–2286. Available at: https://doi.org/10.3390/heritage2030139.

Rabin, J. (2004) ‘Quantification of color vision with cone contrast sensitivity’, *Visual Neuroscience*, 21(3), pp. 483–485. Available at: https://doi.org/10.1017/S0952523804213128.

von Saint-George, C. and Lewerentz, K. (2008) *Gustave Caillebotte – Garden in Trouville, Brief Report on Technology and Condition*, *Research Project Painting Techniques of Impressionism and Postimpressionism*. Köln. Available at: https://forschungsprojekt-impressionismus.de/detail.aspx?lang=en&pg=&kat=kuenstler&id=31&iid=63.

Strlič, M. *et al.* (2013) ‘Damage functions in heritage science’, *Studies in Conservation*, 58(2), pp. 80–87. Available at: https://doi.org/10.1179/2047058412Y.0000000073.

Webb, K. (2019) ‘UV-Induced Visible Luminescence for Conservation Documentation’, in M. Picollo, M. Stols-witlox, and L. Fuster-Lopez (eds) *UV-Vis Luminescence imaging techniques/ Técnicas de imagen de luminiscencia UV-Vis*. Valencia: Editorial Universitat Politècnica de València (Conservation 360, 1), pp. 35–60. Available at: https://doi.org/10.4995/360.2019.110002.

Glazing over grisaille. A multi-band record of pigmented and dyed oil glazes

Aránzazu Llácer-Peiró[3], Serena Hirsch[4], M. Antonia Zalbidea-Muñoz[2], Miquel Àngel Herrero-Cortell [1], Laura Fuster-López[3]

[1] *Departamento de Comunicación Audiovisual, Documentación e Historia del Arte, UPV*

[2] *Departamento de Conservación y Restauración de Bienes Culturales, UPV*

[3] *Instituto Universitario de Restauración del Patrimonio*

[4] *Centro Conservazione e Restauro "La Venaria Reale"*

Corresponding author: Miquel Àngel Herrero-Cortell

ABSTRACT

The present paper addresses the visual and technical study of historical glazes, both organic and inorganic, applied over monochrome grisaille. These glazes were commonly used in painting between the 15th and 17th centuries. The aim of this work is to record the behaviour of these materials when applied as glazes over grisaille (grey tones underneath), as their diverse nature gives very different results. In order to carry out this evaluation, two mock-up panels were prepared in which a wide range of greys were created using lead white and lamp black in varying proportions.

These grisailles served as a base for the application of 32 glazes made with different pigments, lakes and dyes, allowing for a variety of chromatic nuances that made it possible to evaluate material, visual or perceptual aspects. Along the paper, it is possible to observe how glazes can alter, modulate or accentuate the underlying colour, and vice versa, how the underlying colour can affect the appearance of the glaze (not only in the visible band, but also in the UV and IR bands). These mock-ups were created using already obsolete techniques and materials, with the aim of replicating the painting processes of the 15th to 17th centuries with the greatest possible methodological fidelity. This approach allowed the results of the application of glazes to the underlying grisaille to be evaluated visually and empirically.

The resulting layers of paint were characterised in two ways: by colorimetric measurements and by imaging in the visible, UV and IR bands using a multi-modal approach (VIS, UVL, UVR, IR, IRFC). This article is part of a broader research project that includes other works derived from the study of glazes as the focus of its field of study [1].

KEYWORDS Glazes, grisailles, multi-band technique, pigments, colorants.

RECEIVED 05/09/2024; **REVISED** 18/10/2024; **ACCEPTED** 02/11/2024

1. Introduction

The grisaille technique appeared in the Middle Ages to create three-dimensional and volumetric effects in figures and representations and remained popular until the 18th century. Although initially associated with black-and-white painting, from the 15th century onwards, it was used as a tonal primer for fully colouristic paintings, using only one white and one black pigment. Sometimes, however, it involved a very subtle use of colour to lightly tint the gradiations of grey. This method, carried out in several stages, involved the application of glazes or translucent layers of colour over a black and white model (hereafter referred to as grisaille) to define both the shadow and light areas. (Mayer, 1985; Villarquide, 2004; Zalbidea, 2014). The result is the product of the gradual chromatic layering of glazes (Torres, 2015). References to this painting technique can be found in various sources and treatises. For example, both Leon Battista Alberti (1434) and Giovanni Battista Armenini (1586) refer to this technique in their respective treatises on painting. Alberti claims that: "…with white and black, light and shade are expressed in painting, and the other colours become the matter to which the various accidents of brightness or darkness are added" (Alberti, 1435 [according to the edition by Rejón de Silva, 1784, p. 245]). On the other hand, Armenini in *De' veri precetti della pittura* [1586] expands on this concept, stating that: "by virtue of white and black, which create the species of these colors, one draws out everything that is necessary." (Armenini, 1999, pp. 84-85).

2. Materials and methods

The samples were prepared using techniques and materials that faithfully reproduce the painting processes used in the centuries under study. Two panels were prepared with different shades of grey, obtained by mixing lead white and vine black in different proportions.

A total of 32 glazes were applied on two panels over a monochrome grisaille ground (Figures 1 and 2). The support used consisted of two panels measuring 35 x 35 cm, prepared with a ground of gypsum, calcium carbonate, and rabbit-skin glue (Santos, 2005). The grisaille paintings on which the glazes were applied were created by combining lead white and lamp black, bound with linseed oil and mixed in various proportions to obtain a wide range of greys. All the pigments were bound according to historical procedures obtained from original sources. The pigments used in the grisaille (white and black) and the pigments, lakes, and dyes used in the glazes, are listed in Table 1.

At the top of each test panel, an area without any glaze application was left to serve as a control for comparison ("Register"). The pigments, dyes, and lakes used in the glazes were bound with a medium composed of linseed oil and mastic resin, which ensures a suitable balance between absorption and drying, thereby achieving the desired visual effect (Bomford et al., 1995; Zalbidea, 2014).

The varnish used as a medium was prepared with a ratio of two parts linseed oil to one part mastic resin, following the recipe of the monk Theophilus (12th century) as described in his treatise "De diversis artibus" (Dodwell, 1961); this recipe has been reproduced by Zalbidea Muñoz et al. (2022), and by Zalbidea Muñoz and Giner (2017).

Regarding the inorganic pigments, those that are more transparent to create translucent layers have been chosen. The selected dyes and lakes generally have a translucent quality, making them ideal for use as glazes, while other pigments with an opaque nature or with high hiding power were not considered. Taken together, the selected materials form a basic palette that woudl have been used from the 15th to the 17th century.

Table 1. Pigments, colorants and lakes used for the grisailles			
GLAZES			
Nº	Pigment	Company	Reference
1	Lead white	Kremer	46000
2	Reseda	Kremer	36262
3	Lead tin yellow	Kremer	10100
4	Saffron	Artisanal production	
5	Yellow ochre	Kremer	40010
6	Aloe	Kremer	38010
7	Stil de grain	Kremer	37394
8	Minium	Kremer	42500
9	Madder Lake Coral	Kremer	372051
10	Dark brown madder lake	Kremer	372141
11	Carmine naccarat	Kremer	42100
12	Cochineal+soda carbonate	Artisanal production	
13	Cochineal+alum + soda carbonate	Artisanal production	
14	Cochineal+alum+sodium bicarbonate	Artisanal production	
15	Blue Bice	Kremer	10184
16	Azurite	Kremer	10200
17	Ultramarine blue	Kremer	10510
18	Esmalt	Kremer	10000
19	Indigo	Kremer	36002
20	Pastel blue	Artisanal production	
21	Copper acetate + reseda	Artisanal production	
22	Copper acetate	Kremer	44450
23	Chrysocolla	Kremer	10350
24	Malachite	Kremer	10310
25	Sap green	Artisanal production	
26	Celadonite	Kremer	11010
27	Ochre havane	CTS	275
28	Van Dyck brown	CTS	9260
29	Dark purple madder lake	Kremer	37218
30	Vivianite	Kremer	104000
31	Bitumen		
32	Atramentum	Kremer	12030
MONOCHROMATIC BASES			
Pigment		Company	Reference
Lead white		Kremer	46000
Vine Black, German		Kremer	47000

Table 1. Pigments, dyes and lakes used in the grisailles

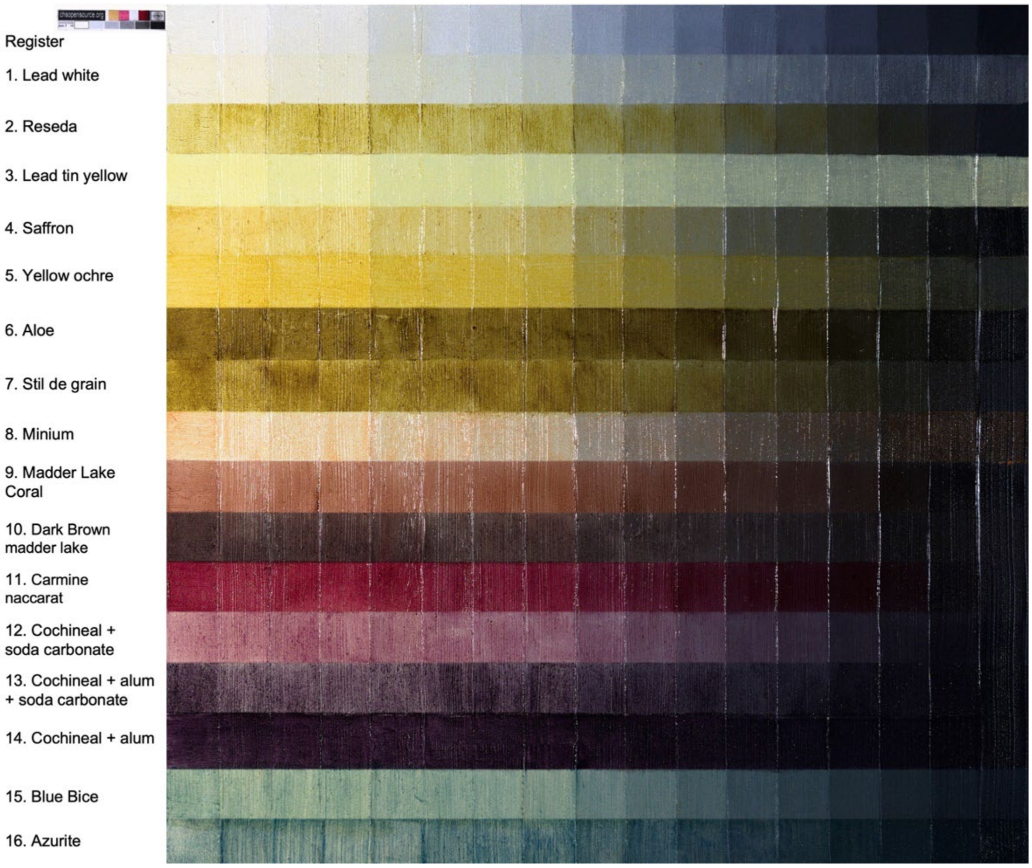


Fig 1. Visible image (VIS) of Test Panel 1.

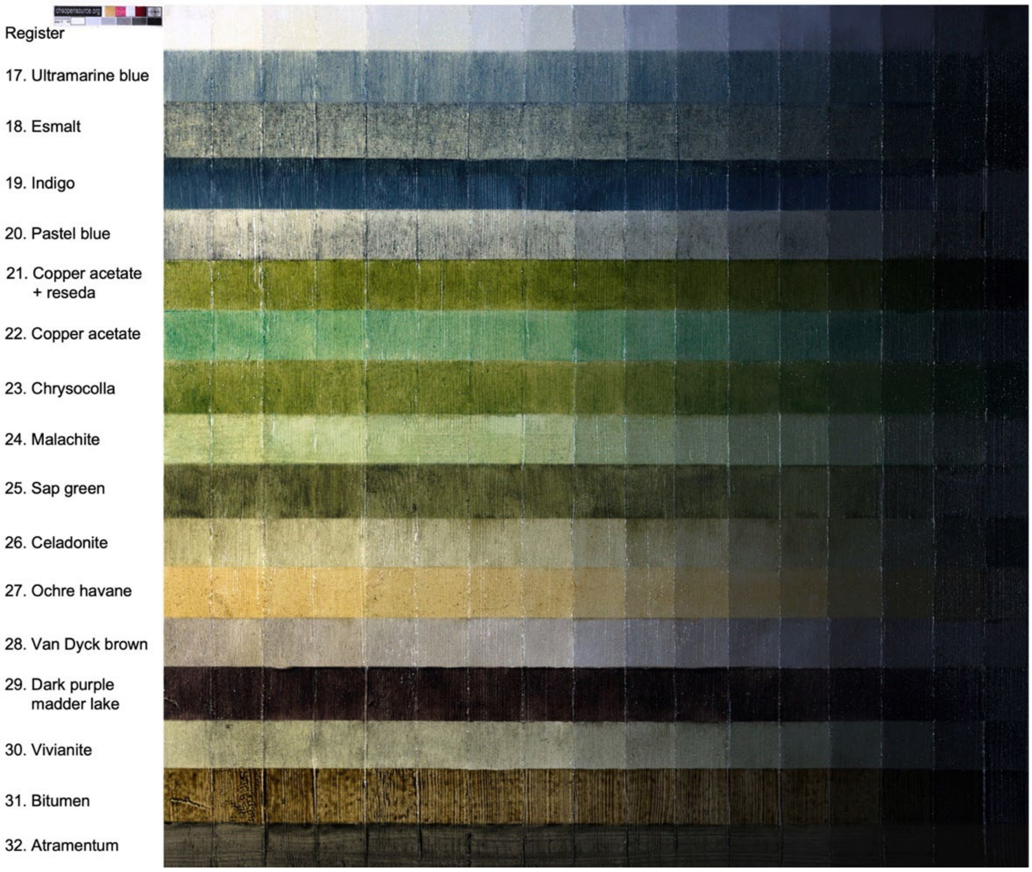


Fig 2. Visible image (VIS) of Test Panel 2.

It was found that the quantification of the mixtures of varnishes, pigments, and dyes with the binder is extremely complex due to the influence of environmental conditions on the result. They were worked and adjusted on the palette to obtain the right fluidity and opacity, avoiding excess oil and ensuring that the pigment did not overly cover the underlying grisaille too much. This experimental phase was mainly based on sensory perception and organoleptic evaluation, considering factors such as colour, the rheological behavior of the paint, and its handling properties.

The characterisation of these glazes has been approached using non-invasive techniques such as colorimetry and multi-band imaging technique. Surface microscopy and FORS spectroscopy were also performed, the results of which are not included in this article. Colorimetry allows for the quantitative, numerical, and objective characterisation of the properties of a colour based on three parameters: hue, lightness, and saturation (Salinas and Hatchondo, 2005). The exact chromatic composition of the glazes was recorded through colorimetric analysis. This digitisation system is as a fundamental tool in the strategies for the conservation and dissemination of cultural heritage, as it allows the identification and monitoring of the chromatic changes that materials undergo due to different factors (Pereira, 2018).

The measurements were conducted using the i1Pro X-Rite® spectrophotometer with D50 illumination, in accordance with the CIE 015:2018 standard, which has long been widely recognized and adopted, particularly in the field of graphic arts, as a reference standard. [2]. The measurement area diameter was 4.5 mm, without a specular component (SCE), in CIELab space. The data were captured using the i1Profiler® v1.8.2 software. Three measurements were taken per area, and the results were averaged (Table 2 and 3).

Colorimetric data of TEST PANEL 1						
Colorant, pigment, lake	Slab area	**L*** (brightness)	**a*** (positive value = degree of red negative value = degree of green)	**b*** (positive value = degree of yellow negative value = degree of blue)	**C*** CROMA (saturation)	**hº** (tone)
Register	1	92	-0,11	17,84	17,84	90,36
	2	70,7	-2,31	2,8	3,63	129,55
	3	28,76	-0,53	-1,48	1,57	250,34
1. Lead white	1	91,17	0,29	23,81	23,81	89,3
	2	72,01	-3,17	9,98	10,47	107,61
	3	42,81	-2,06	0,35	2,09	170,44
2. Reseda	1	83,91	2,66	46,9	46,98	86,75
	2	60,65	2,05	40,91	40,96	87,13
	3	28,98	-0,68	6,5	6,53	95,95
3. Lead tin yellow	1	89,4	-2,56	45,47	45,54	93,23
	2	75,89	-6,15	29,91	30,54	101,62
	3	61,34	-5,9	20,14	20,99	106,34
4. Saffron	1	85,04	6	47,1	47,48	82,74
	2	65,09	1,78	34,21	34,26	87,02
	3	20,34	-1,38	6,5	6,65	101,97
5. Yellow ochre	1	83,72	9,29	52,92	53,73	80,04
	2	66,13	3,95	39,74	39,93	84,33
	3	32,79	-1,3	13,2	13,27	95,63
6. Aloe	1	54,51	16,47	51,01	53,61	72,11
	2	44,19	10,87	40,17	41,61	74,86
	3	17,88	1,31	9,58	9,67	82,22
7. Stil de grain	1	65,59	14,37	54,65	56,5	75,27
	2	48,75	11,37	36,61	38,33	72,75
	3	24,8	1,14	7,31	7,4	81,16
8. Minium	1	85,67	10,5	30,95	32,68	71,26
	2	66,11	3,59	17,35	17,72	78,32
	3	29,27	7,52	10,09	12,58	53,29
9. Madder Lake Coral	1	67,62	23,65	27,32	36,14	49,12
	2	52	17,67	18,75	25,76	46,69
	3	16,72	4,57	4	6,07	41,15
10. Dark brown madder lake	1	41,33	20,15	14,54	24,85	35,82
	2	42,2	10,81	9,97	14,7	42,69
	3	20,41	5,97	3,52	6,93	30,51
11.Carmine naccarat	1	50,01	48,59	18,63	52,04	20,97
	2	39,35	36,78	10,09	38,14	15,34
	3	15,71	10,48	2,07	10,69	11,16
12.Cochineal + soda carbonate	1	69,38	24,15	13,71	27,77	29,58
	2	56,93	13,87	5,54	14,94	21,77
	3	18,42	4,07	-0,47	4,1	353,38
13.Cochineal + alum + soda carbonate	1	44,73	19,63	3,74	19,98	10,78
	2	42,75	11,68	0,58	11,69	2,82
	3	14,53	3,63	-1,1	3,79	343,19

Colorimetric data of TEST PANEL 1						
Colorant, pigment, lake	Slab area	L* (brightness)	a* (positive value = degree of red negative value = degree of green)	b* (positive value = degree of yellow negative value = degree of blue)	C* CROMA (saturation)	hº (tone)
14.Cochineal + alum + sodium bicarbonate	1	31,9	26,34	-0,07	26,34	359,83
	2	23,34	19,34	-0,93	19,36	357,23
	3	14,74	4,34	-1,38	4,55	342,32
15.Blue Bice	1	73,56	-12,38	16,34	20,5	127,14
	2	63,96	-9,25	8,85	12,8	136,29
	3	28,44	-3,53	0,06	3,53	178,98
16.Azurite	1	76,45	-8,27	13,41	15,75	121,66
	2	51,06	-12,54	2,78	12,85	167,51
	3	22,96	-5,22	-1,83	5,53	199,34

Table 2. Colorimetric data obtained from Test Panel 1.

Colorimetric data of TEST PANEL 2						
Colorant, pigment, lake	Slab area	L* (brightness)	a* (positive value = degree of red negative value = degree of green)	b* (positive value = degree of yellow negative value = degree of blue)	C* CROMA (saturation)	hº (tone)
Register	1	90,93	-0,34	15,19	15,2	91,29
	2	70,11	-2,31	3,51	4,2	123,42
	3	29,26	-0,6	-0,47	0,76	218,21
17. Ultramarine blue	1	65,54	-6,95	9,54	11,8	126,07
	2	52,94	-7,22	2,78	7,74	158,97
	3	21,33	-2,08	0,01	2,08	179,86
18. Esmalt	1	61,71	-4,11	15,71	16,23	104,67
	2	49,22	-5,02	4,89	7,01	135,79
	3	19,71	-1,73	0,87	1,94	153,31
19. Indigo	1	32,78	-7,73	-4,19	8,8	208,48
	2	32,46	-6,35	-0,65	6,38	185,85
	3	23,22	-0,64	-1,81	1,92	250,58
20. Pastel blue	1	77,31	-1,64	23,25	23,31	94,04
	2	63,88	-3,3	9,49	10,04	109,16
	3	23,25	-1,17	1,24	1,71	133,33
21. Copper acetate + reseda	1	62,45	-5,03	49,15	49,41	95,84
	2	45,29	-8,09	42,46	43,22	100,79
	3	12,2	-3,96	12,08	12,71	108,14
22. Copper acetate	1	62,92	-22,4	33,82	40,57	123,53
	2	54,24	-17,87	24,15	30,04	126,49
	3	17,76	-6,54	4,44	7,91	145,86
23. Chrysocolla	1	59,85	-9,48	41,93	43	102,74
	2	51,03	-9,14	33,58	34,8	105,23
	3	21,63	-9,55	12,06	15,38	128,38
24. Malachite	1	71,23	-9,27	37,76	38,89	103,8
	2	62,14	-8,56	21,85	23,46	111,39
	3	28,07	-3,71	5,18	6,37	125,6
25. Sap green	1	56,7	1,23	35,65	35,67	88,03
	2	42,79	-0,66	24,49	24,5	91,54
	3	22,87	-0,48	2,99	3,03	99,07
26. Celadonite	1	68,02	2,17	35,68	35,75	86,52
	2	58,45	-1,59	22,57	22,63	94,03
	3	21,96	-1,81	5,37	5,67	108,65
27. Ochre havane	1	75,93	9,12	40,62	41,63	77,34
	2	61,4	3,17	26,28	26,46	83,11
	3	25,43	-0,26	6,68	6,68	92,19
28. Van Dyck brown	1	67,35	4,24	21,42	21,83	78,81
	2	60,65	-0,24	8,8	8,8	91,54
	3	26,69	0,21	1,05	1,07	78,67
29. Dark purple madder lake	1	31,18	13,95	12,99	19,06	42,95
	2	23,92	9,51	7,81	12,31	39,4
	3	16,71	1,46	0,73	1,63	26,6
30. Vivianite	1	72,94	-0,01	29,6	29,6	90,02
	2	58,31	-3	17,22	17,48	99,88
	3	21,95	-1,61	3,6	3,94	114,02
31. Bitumen	1	53,25	12,71	39,28	41,29	72,07
	2	43,79	7,21	27,46	28,39	75,28
	3	13,6	1,48	6,85	7,01	77,84
32. Atramentum	1	59,13	3,2	22,55	22,77	81,91
	2	40,61	0,95	13,55	13,58	85,98
	3	14,72	-0,17	1,85	1,86	95,38

Table 3. Colorimetric data obtained from Test Panel 2

This study adopts a scientific and technical approach utilizing the multi-band technique, which captures images across different bands of the electromagnetic spectrum using the same device. The various images obtained through this technique provide valuable insights when analyzed individually. However, by comparing the results from the joint interpretation of these images, preliminary conclusions can be drawn regarding the presence or absence of certain materials, as well as their characteristics. (Herrero-Cortell et al., 2018; Artoni et al., 2019).

Photographs taken in the visible spectrum (VIS) provide information about chromaticity, tonality, and surface condition. Conversely, infrared (IR) photography reveals underlying drawings and the behaviour of pigments under infrared radiation, identifying possible pentimenti (Cosentino, 2016). Ultraviolet (UVL) photography, on the other hand, detects retouches, overpaints, as well as varnishes and pigments that fluoresce (Cosentino, 2015a). False color infrared photography (IRFC) helps to identify pigments by combining infrared and visible images. Although they do not provide definitive conclusions, they do support or generate hypotheses about the presence of certain materials (Cosentino, 2016).

A modified Nikon® D800 full-spectrum camera was used to capture the images, allowing information to be collected in the visible spectrum, part of the infrared spectrum, and part of the ultraviolet spectrum. For visible photography, an X-Nite CC1 filter was used to block out the IR and UV range. Pro-Foto 1250 W halogen lamps were used for lighting. The X-Nite CC1 filter was again used for visible photography under UV excitation (UVL). The light source was a 365 nm ultraviolet lamp with a pass filter for the UV range only (200-400 nm). For infrared (IR) photography, the Heliopan-1000 filter was used.

3. Results and discussion

3.1. *Colorimetry*

Measurements were taken in three representative areas: the lightest, the middle, and the darkest (Figure 3). The data obtained are presented in Tables 2 and 3, and they illustrate the changes experienced by each glaze applied over the grisaille.

3.1.1. Hiding Power and Brightness

Pigments differ in their ability to cover the underlying color. lead tin yellow (3), dark brown madder lake (10), cochineal (14), indigo (19), and dark purple madder lake (29) have a high hiding power. This visually perceptible characteristic (Llácer-Peiró et al., 2023) is also reflected in the colorimetric data, as the data indicate that this deviation is much less significant compared to the other glazeseven if there is a considerable change in brightness from areas over white grisailles to darker areas, (Figure 3). On the other hand, Reseda (2), Saffron (4), Minium (8), and Pastel Blue (20) have a more limited opacity (as noted by Díaz, 2022; Llácer-Peiró et al., 2023), resulting in a significant change in the brightness of the grisailles as the underlying colour becomes darker (Figure 3).

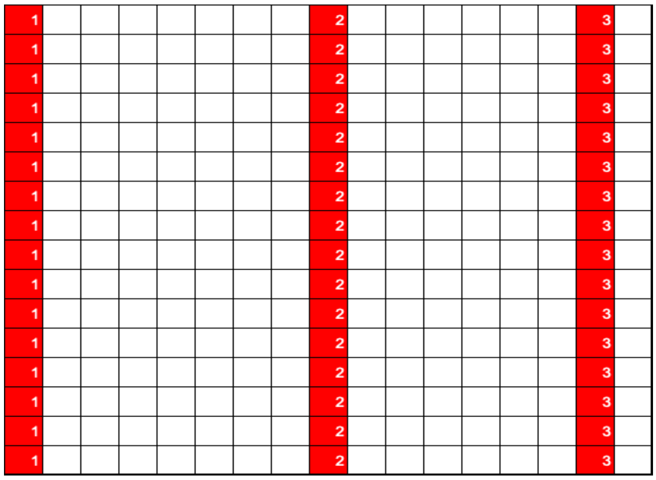


Fig 3. Localisation of the areas where colourimetry has been carried out on the panels

3.1.2. Effect on the underlying color

Glazes are significantly influenced by the underlying color. The a* coordinate shows a tendency for most glazes to shift towards green tones (-a*) as the tone of the underlying grisaille becomes darker. In this regard, red glazes such as madder lake coral (9), dark brown madder lake (10), carmine naccarat (11), and Cochineal (12, 13, and 14) are the ones with the most significant shift towards green tones (-a*), although this change is not visually perceptible. Only glazes made with blue pigments (15-22 and 24) and, exceptionally, malachite (24) show a tendency towards red tones (+a*). The b* coordinate indicates a shift towards blue tones for all the glazes (-b*), made of yellow pigments such as reseda (2), saffron (4), yellow ochre (5), aloe (6), stil de grain (7), and ochre havane (27) showing the greatest increase. The indigo glaze (19) is the only one that shows a slight shift towards yellow tones (+b*).

3.1.3. Tonal changes

While all pigments and dyes show changes depending on the underlying colour, some of them show significant chromatic transitions. For example, Lead White (1) has colorimetric values that indicate a significant tonal shift from yellow to green, although visually, bluish tones are perceived in the darker areas of the glaze. Another relevant case is cochineal 12 and 13, whose hues vary from reddish tones when the glaze is applied over light tones to bluish shades in darker areas. Blue bice (15) and azurite (16) also undergo a significant change from green to bluishtones as the underlying grisaille darkens.

3.1.4. Colour dominance

Although visual perception may suggest a predominant colour, colorimetric data reveal the true chromatic composition of the glaze. For example, Blue Bice (15) and Azurite (16) may appear bluish visually, but colourimetry shows a predominance of green and yellow hues.

3.2. *Multi-band technique*

The two mock-ups (Figures 1 and 2) were subjected to multiband imaging (VIS, IR, UVL) and false-color infrared (IRFC) to observe the behavior of the different materials studied. In particular, the aim was to show how the presence of different levels of grey used as grisaille can influence pigments, lakes, or dyes applied as glazes, even beyond the visible range. The results of the multiband imaging techniques used are detailed below.

3.2.1. VIS

Visible images (Figures 1 and 2) were used as a reference for UVL, UVR, IR, and IRFC images to observe the color based on the underlying grisaille. Where an underlying white layer is present, the colors appear very bright and clear. Over darker grey levels, the color tends to become less saturated until it appears almost completely black, which is confirmed by the colorimetric results. The exception to this is lead tin yellow (3), which retains its dominant color component over the underlying color due to its high opacity.

3.2.2. UVL

The phenomenon of UV-induced luminescence may depend on many factors such as the thickness of the brushstroke, the presence of an underlying material that may have its own luminescence, the type of binder or the presence of any varnish (Herrero-Cortell M. Á. *et al.*, 2022).

Some pigments emit their own characteristic luminescence, such as lead white (1), which tends toward a light blue tint, or ultramarine blue (17), which has a bluish appearance. (Herrero-Cortell M. Á. *et al.*, 2022).

Observation of the UVL images (Figures 4 and 5) shows that the different shades of grey under the pigment layers do not significantly alter the characteristic luminescence of the material. In fact, where the grisaille has light grey tones, the colours show almost unchanged and clearly distinguishable luminescence. With darker shades of grey, the luminescence is less pronounced but still clearly visible. Only in the case of some pigments, especially greens and blues, the last square in the row, where the grisaille is very dark, tends to be difficult to interpret. Finally, it should be noted that copper acetate + yellow (21), copper acetate (22), and dark purple madder lake (29) do not emit any luminescence, regardless of the grey tone of the underlying background, and therefore appear black (Fuster-López et al., 2023). Although lead white (1) and lead tin yellow (3) have a similar response to the visible light, their behavior in UVL photography is the opposite: lead white (1) is luminescent while lead tin yellow (3) is absorptive. (Díaz, 2022).

3.2.3. UVR

The image obtained with reflected UVR is useful for the identification of white pigments, such as zinc white or titanium white, which are highly absorbent. Similarly lead white and lithopone can be identified due to their high reflectivity (Cosentino, 2015b). However, this technique is not particularly useful for identifying other pigments. The presence of an underlying grisaille (Figures 6 and 7) does not significantly affect the result. In fact, the analysis of each colour row shows grey levels that are largely independent when moving from lighter to darker hues. It is interesting to note that the last three squares correspond to very dark grey tone, result in a slight change in the contrast. Lead white (1) always appears as a light grey tone and only tends to darken slightly in the presence of darker backgrounds.

3.2.4. IR

By observing the IR images, it is possible to see what is underneath the different color fields, based on their transparency to IR radiation (Cosentino, 2015b).

In this case (Figures 8 and 9), most of the pigments analysed appear quite transparent to IR radiation. In fact, the observed grey levels are mainly due to the different backgrounds used to create the underlying grisaille (white to black). Most of the organic pigments (2, 4, 5, 6, 7, 9, 10, 12, 13, 14, 19, 20, 25) exposed to IR radiation appear as transparent materials, allowing perfect observation of the underlying grisaille gradations. Only in the case of *Atramentum* (32) were contrasts between the different glaze layers visible in IR (Llácer Peiro, 2021).

Copper acetate + yellow (21), copper acetate (22), chrysocolla (23), malachite (24) and aloe (6) show an intermediate behavior and therefore the levels of grey that are observed follow the trend of the underlying grisaille, but the tone that is observed is partially influenced by the pigment itself.

Interestingly, lead tin yellow (3) has a high hiding power, and does not allow the observation of the grisaille obtained with dark tones (Kühn, 1968).

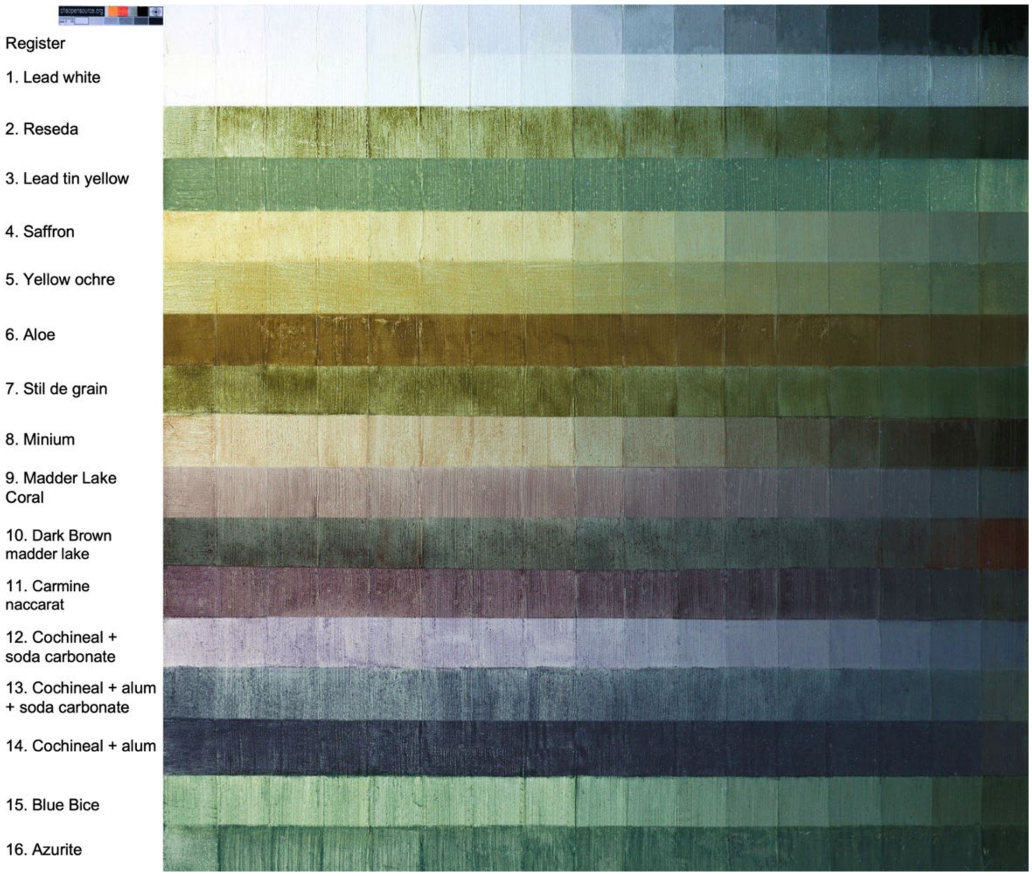


Fig. 4. UVL image of Test Panel 1.

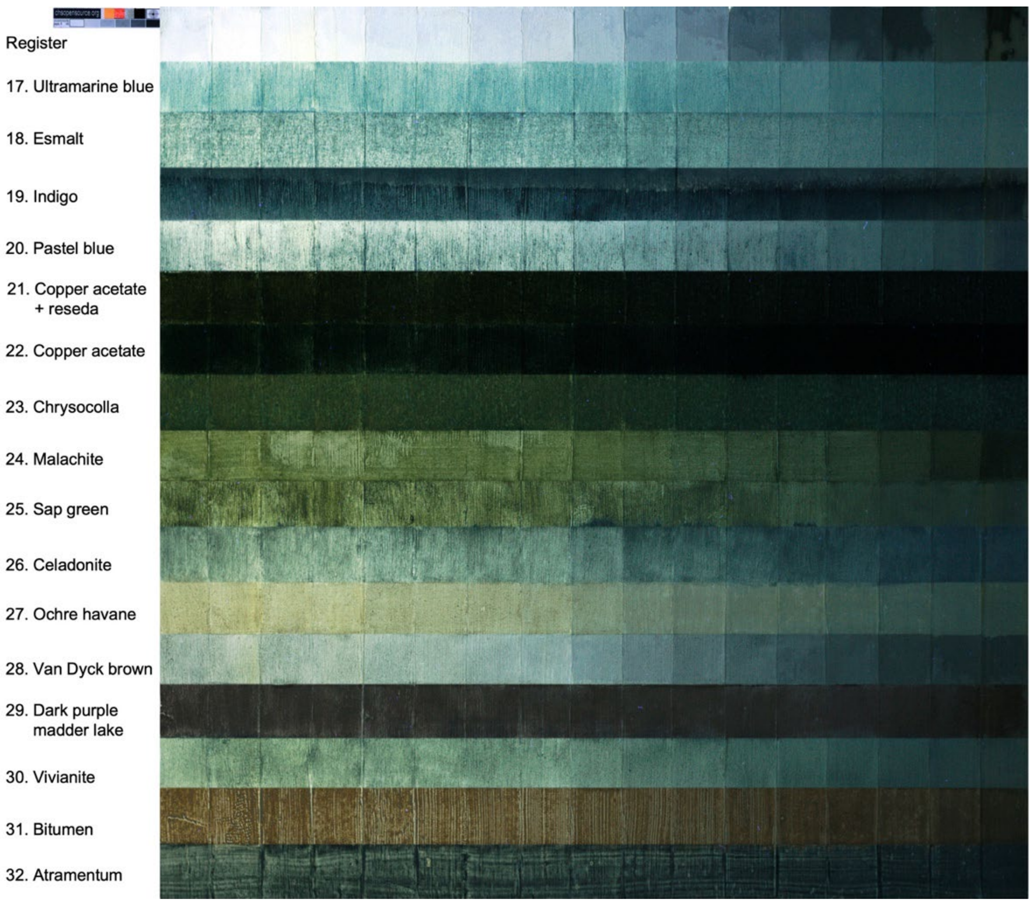


Fig. 5. UVL image of Test Panel 2

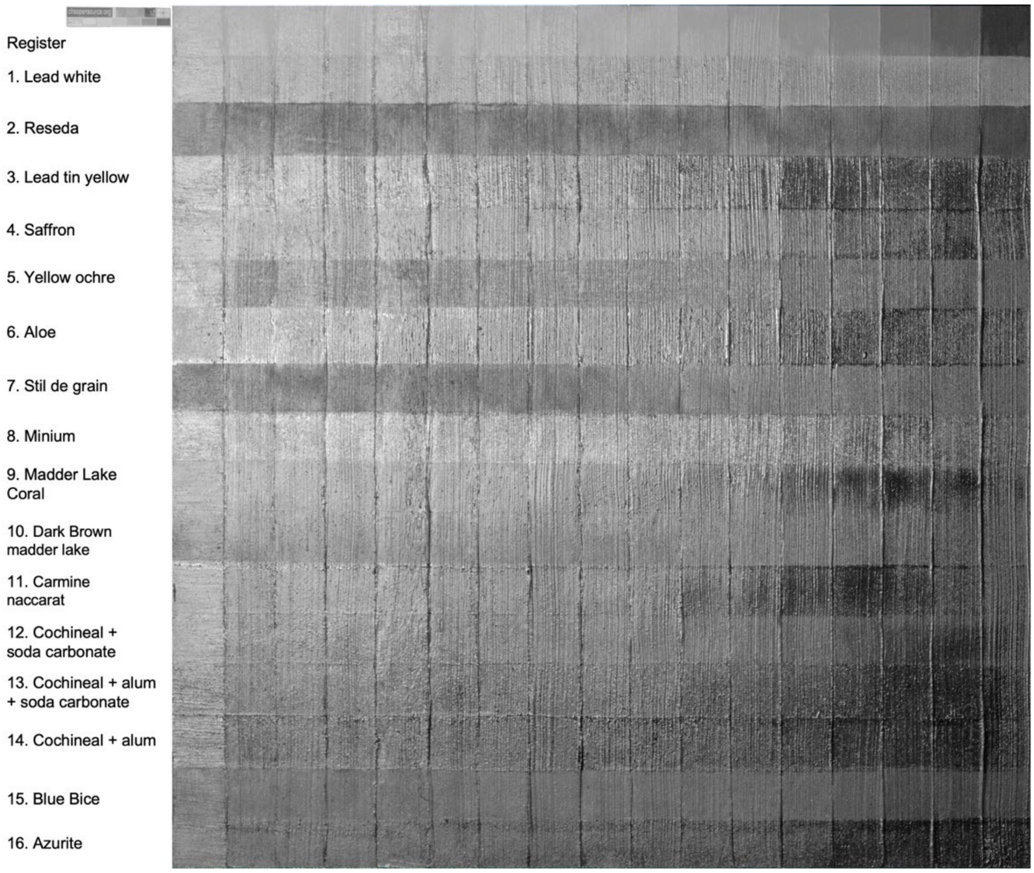


Fig. 6. UVR image of Test Panel 1

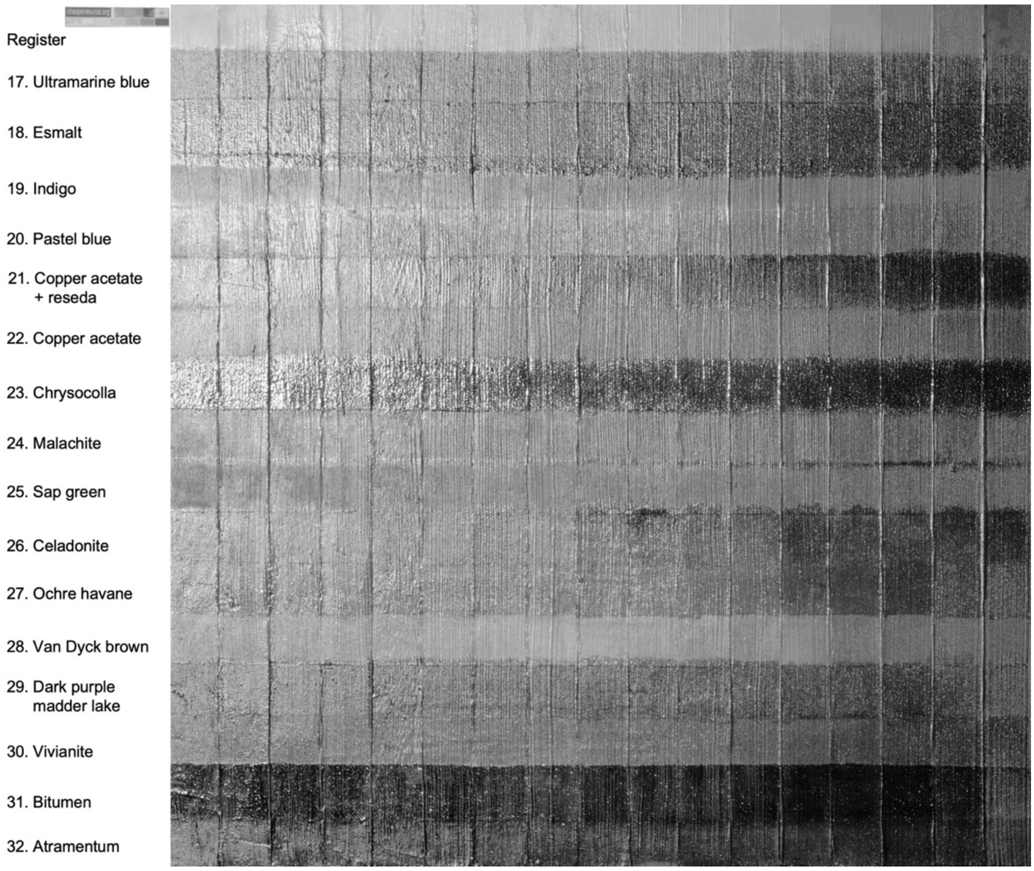


Fig. 7. UVR image of Test Panel 2.

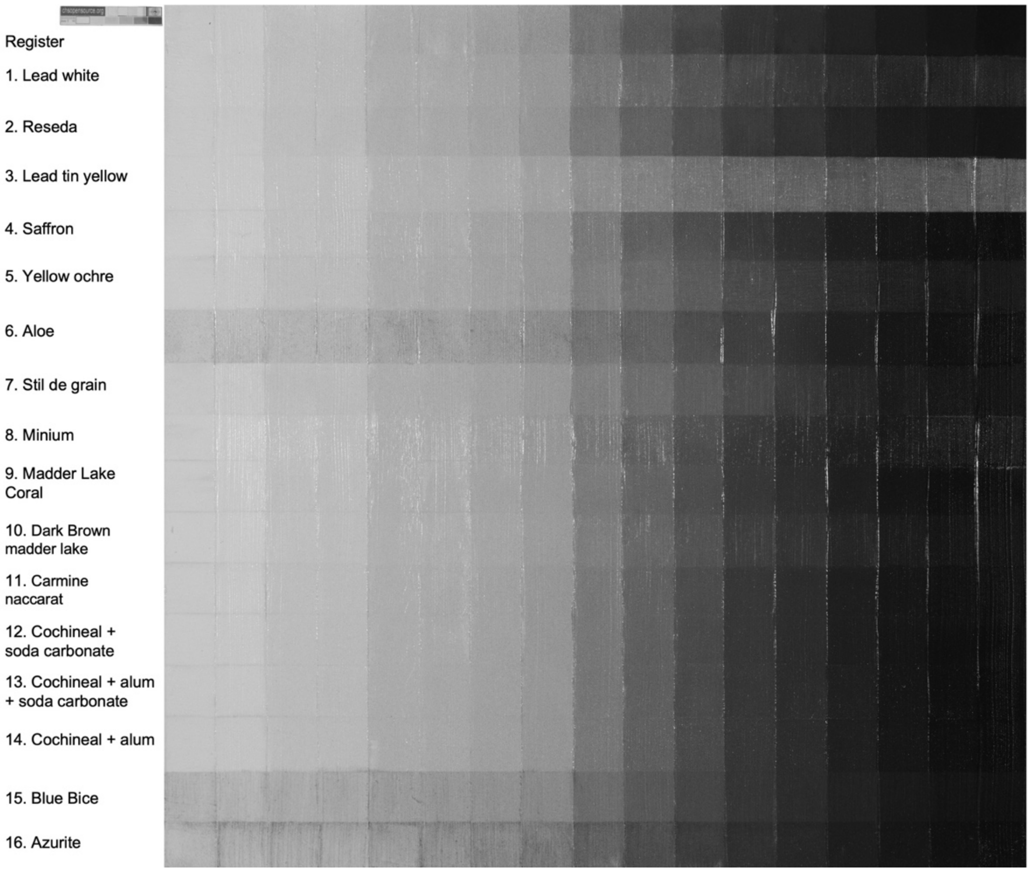


Fig. 8. IR image of Test Panel 1.

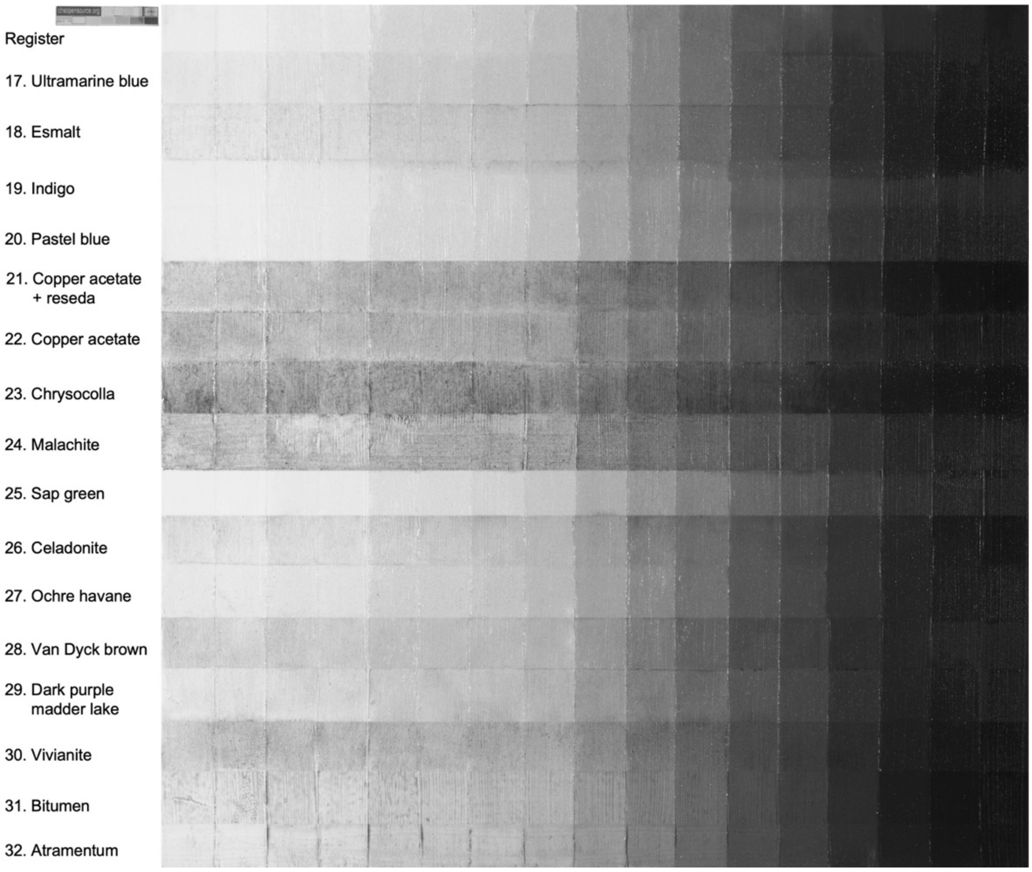


Fig. 9. IR image of Test Panel 2

3.2.5. IRFC

False colour infrared is a technique that makes it possible to discriminate between pigments that have similar optical behaviour under visible illumination but different IR reflectance (Aldovrandi & Picollo, 2007).

Observing the images in IRFC (Figures 10 and 11), it can be seen that the color areas obtained on a light ground do not show significant changes in the characteristic false colour. The colours superimposed on darker grisaille, tend to be less and less saturated becoming almost black, as can be seen in the last two areas of each row. Once again, lead tin yellow (3), thanks to its hiding power, allows the characteristic false colour to be observed even over areas of very dark grey.

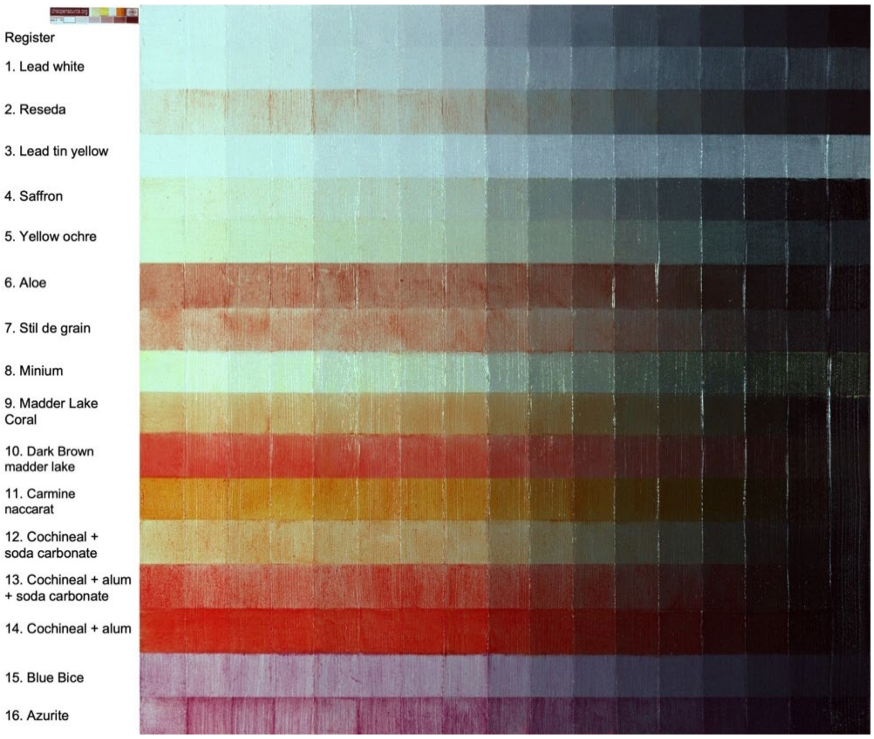


Fig. 10. IRFC image of Test Panel 1

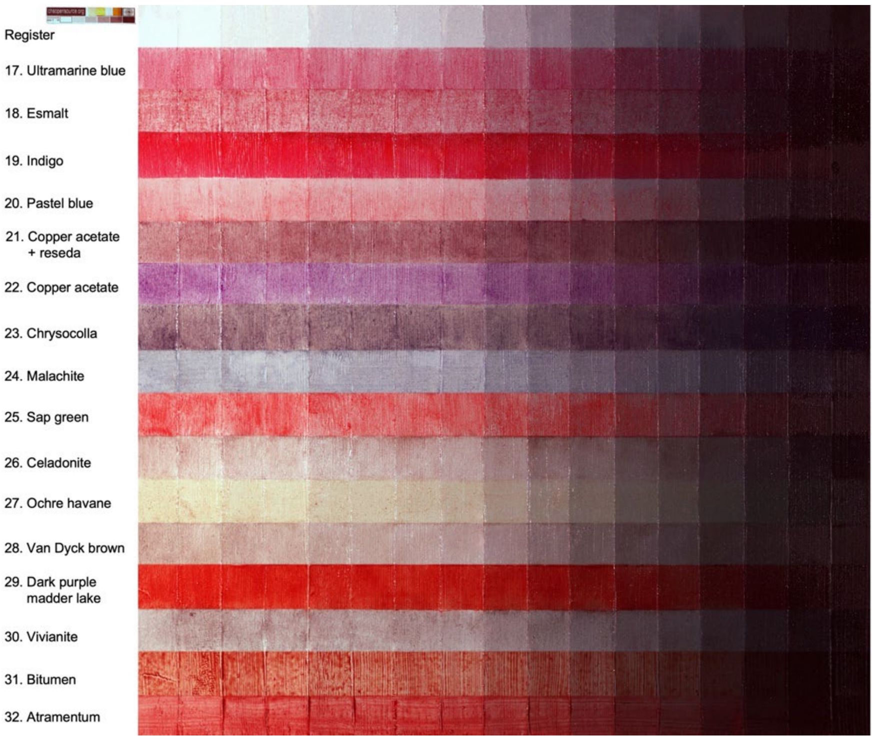


Fig. 11. IRFC image of Test Panel 2

4. Conclusions

This text presents a study of the use of historical glazes - both organic and inorganic-, applied over monochrome grisailles as used in painting between the 15th and 17th centuries. To achieve this, a visual analysis was carried out using a wide range of pigments, lakes and dyes to obtain different chromatic nuances. The main objective was to evaluate the impact of monochromatic underlying grisailles on the upper glazes.

All the processing and creation work on the pictorial material was characterised both visually and quantitatively by means of colourimetric measurements and multi-band techniques. Colorimetric analysis revealed an inverse relationship between hiding power and changes in luminosity. That is, opacity correlates with less variation in luminosity. On the other hand, glazes were found to shift colour being the most common shifts towards green tones. Significant tonal changes were observed in some pigments, such as chromatic transitions from yellows hues to greens (lead white) or from reds to blues (cochineal 12 and 13).

Finally, it should be noted that, although visual perception may suggest a predominant colour, the colorimetric data revealed the true chromatic composition of the glazes, highlighting that some pigments have a colour dominance different from that perceived, as seen with blue bice (15) and azurite (16). The observation of the multi-band images showed how the colour of the glazes changed depending on the grisaille underneath. UVL and UVR did not show any significant changes in the hues of the various pigments, except for areas on very dark grisailles where the colour tended to turn to black. In addition, many colours were quite transparent to the IR radiation, allowing the underlying grisaille to be seen. Finally, the IRFC showed an overall effect of the dark grisaille on the individual pigments, which in most cases makes it difficult to identify them.

This study has shown that grisailles have a significant impact on the perception of the glazes applied over them. These varnishes modify and nuance the tones upon which they are applied, hence the importance of considering these layers in the conservation of paintings.

5. Conflict of interest declaration

The authors wish to state that no financial or personal interests have affected the objectivity of the study, and that no conflicts of interest exist.

6. Funding source declaration

This research has been carried out within the framework of the PID 2019-106616ES-100 project awarded by MCIN/ AEI /10.13039/501100011033.

7. Short biography of the author(s)

Aránzazu Llácer-Peiró - Research Technician pursuing the PhD in Conservation at Instituto Universitario de Restauración del Patrimonio (Universitat Politècnica de València) on the study of drying pigments through a multi-analytical approach.

Serena Hirsch - Master degree in Science and Materials for Conservation and Restoration of Cultural Heritage from the University of Florence. She conducted her MA thesis research on diagnostic techniques, in particular on multi-band imaging applied to paintings. She currently works as a scientific assistant at La Venaria Reale Conservation and Restoration Centre.

Mª Antonia Zalbidea-Muñoz - Professor in the Department of Conservation and Restoration of Cultural Heritage at the UPV, field in which she holds a doctorate degree. She has directed her research towards the procedural, material and conservative aspects of mural paintings, as well as to the use of varnishes and dyes in paintings. She is currently a member of the project team: B*yzantine illuminated manuscripts in Spain: work, context and materiality - MABILUS* (MICINN-PID2020-120067GB-I00).

Miquel Àngel Herrero-Cortell - He holds a PhD in Art History. He has a degree in Fine Arts from the Polytechnic University of Valencia (UPV) and a degree in Art History from the University of Valencia (UV). He holds a Master's Degree in Conservation and Restoration of Cultural Heritage and a Master's Degree in Artistic Production. He has developed his work as a researcher focusing on the field of materials and painting techniques, as well as on painting diagnosis. He is currently lecturer at the Universitat Politécnica de València.

Laura Fuster-López - Professor at the Conservation Department in the Universitat Politècnica de València (Spain). After several research fellowships at Europe and the United States, she got her PhD in Conservation from UPV where she coordinates the area on the study of the mechanical and dimensional properties of cultural materials since 2007. She has been involved in numerous international R+D projects always with a special focus on understanding the mechanisms involved in paintings behavior and degradation.

Notes

[1] Below are the works derived from the study of glazes:

Llácer-Peiró, A; Zalbidea-Muñoz, M.A.; Fuster-López, L. (en prensa). Natural dyes and lake pigments used for glazing in the Middle Ages. From sources to archaeological reconstructions.

Herrero-Cortell, M. À., Raïch, M., P. Artoni, Madrid García, J. (2022). Caracterización de pigmentos históricos a través de técnicas de imagen, en diversas bandas del espectro electromagnético. *Ge-Conservación*, 22(1), 58-75. https://doi.org/10.37558/gec.v22i1.1101

Herrero-Cortell, M. À., Artoni, P., Picollo, M., Raïch, M., Zalbidea, M.A. (2021). The Changes of Transparent Colours in Being Laid upon Others: Considerations for a New Perception of Glazes with Historical Pigments and Dyes. *Color Culture and Science Journal,* 13(2), 64-71. https://jcolore.gruppodelcolore.it/ojs/index.php/CCSJ/article/view/262/214

Herrero-Cortell, M. À., ArtonI, P., M., Raïch, M. (2020). Transmitted light imaging in VIS and IR, in the study of paintings: a brief report on the behavior of the main historical pigments. *Cultura e Scienza del Colore - Color Culture and Science*, 12(2), 79-88. https://doi.org/10.23738/CCSJ.120210

Herrero-Cortell, M.À., Llácer-Peiró, A., Zalbidea-Muñoz, M.A., Fuster-López, L. (2023). Investigación, docencia y transferencia en torno a la paleta pictórica de la Edad Moderna. Teoría, práctica y caracterización científica de veladuras con pigmentos orgánicos e inorgánicos. [Communication]. II *Jornadas de Buenas Prácticas en Investigación y Docencia del Color.*

Llácer-Peiró, A., Herrero-CortelL, M.À., Zalbidea-Muñoz, M.A., Fuster-lópez, L. (2022, septiembre 12-13). Trasparenze naturali. Velature storiche prodotte con pigmenti-lacca e coloranti organici [Comunicación*]. XVII Conferenza del Colore, (Florencia, Italia).*

Llácer-Peiró, A., Herrero-CortelL, M.À., Zalbidea-Muñoz, M.A., Fuster-lópez, L. (2022, octubre 17-19). Estudio no invasivo mediante técnicas de imagen multibanda de pigmentos laca y colorantes en veladuras históricas [Communication]. *IX Edición Congreso Ciencia y Arte.* Madrid.

Llácer-Peiró, A., Herrero-CortelL, M.À., Zalbidea-Muñoz, M.A., Fuster-lópez, L. (2022). Trasparenze naturali. Velature storiche prodotte con pigmenti-lacca e coloranti organici. *Colore e Colorimetria Contributi Multidisciplinari, XVII Conferenza del Colore. XVII* B(20-28). https://www.rcasb.eu/index.php/RCASB/catalog/view/8/10/190

Díaz Mata, L.; Herrero-CortelL, M. A., Zalbidea-Muñoz, M.A. (2022). Velatura sotto la lente d'ingrandimento: l'osservazione dei pigmenti storici al microscopio di superficie. *Colore e Colorimetria Contributi Multidisciplinari, XVII Conferenza del Colore. XVII* B (29-35). https://www.rcasb.eu/index.php/RCASB/catalog/view/8/10/190

Herrero-Cortell, M.A, Raïch, M., Zalbidea, M.A., Artoni, P., Picollo, M. y La Bella, A. (2020). Della mutazione de' colori trasparenti': per una rinnovata percezione delle velature dei pigmenti e dei coloranti storici. *Colore e Colorimetria Contributi Multidisciplinari, XVI* A (125-132). https://www.gruppodelcolore.org/wp-content/uploads/2020/11/ColoreEcolorimetriaContributiMultidisciplinari_VolXVIA-1.pdf

Artoni, P. Herrero-Cortell, M.À. Raïch, M.; Ricci, M. L. (2019). Riconoscere dal colore. Pigmenti e coloranti dell'età moderna nell'analisi multibanda dei dipinti: uno strumento visivo per gli storici dell'arte e i conservatori. *Colore e Colorimetria. Contributi multidisciplinari,* XVA (120-127)
https://www.unisob.na.it/ateneo/restauro/attivita8_megnac_2.pdf

Herrero-Cortell, M. À., Artoni, P., M., Raïch, M. (2019). Luce attraverso il colore: il comportamento di alcuni pigmenti storici nei dipinti su tela in luce trasmessa nel visibile e in infrarosso (TL e IRT). *Colore e Colorimetria. Contributi multidisciplinari,* XVA (104-111). https://www.unisob.na.it/ateneo/restauro/attivita8_megnac_2.pdf

Díaz Mata, L. (2022). *Veladuras con pigmentos inorgánicos (ss. XV-XVIII). Reconstrucción experimental y caracterización multi-técnica* [Master Thesis, Universitat Politècnica de València]. http://hdl.handle.net/10251/186375

Llácer-Peiró, A. (2021). *Veladuras históricas con pigmentos laca. Aproximación teórico-práctica y caracterización en diversas bandas del espectro* [Master Thesis, Universitat Politècnica de València]. http://hdl.handle.net/10251/173723

Gollini, G. (2020*). Potenzialità della tecnica di imaging iperspettrale per lo studio di pitture a olio in presenza di velature* [Master Thesis, Università degli studi di Firenze].

Pedret, A. V. (2018). *"Bones e fines": pigmentos y lacas en la pintura catalana del siglo XV* [Degree Final Project, Universitat de LLeida].

Zalbidea Muñoz, M. A., Molinari, M and Herrero-Cortell, M.A. (2024) "Mutazione del colore per invecchiamento delle resine natural". *Colore e Colorimetria*. Contributi Multidisciplinari. Vol. XVIII B Pp. 111-119 https://flore.unifi.it/retrieve/ed48e7f4-d482-4ef0-88a5-917236e21a1d/Proceedings_CdC2023_ITA-VolXVIIIB_scalzo.pdf

[2] For more information, see Melgosa, M. (2020). "Revisión de algunos conceptos de ciencia del color relacionados con la iluminación" Luces CEI No. 70, 16-21.

Licensing terms

References

Aldrovandi, A., Picollo, M. (1999), *Metodi di documentazione e indagini non invasive sui dipinti*, (2007 seconda edizione).

Armenini, G.B. (1999) *De los verdaderos preceptos de la Pintura* (1586/7), intr. y not. M.C. Bernárdez Sanchís, Visor Libros, Madrid. Armenini, G.B. (1988) *De'veri precetti della pittura*, Giulio Einaudi, Turín.

Artoni, P.; Herrero-Cortell, M.A.; Raïch, M. *et al* (2019): «Riconoscere dal colore. Pigmenti e coloranti dell'età moderna nell'analisi multibanda dei dipinti: uno strumento visivo per gli storici dell'arte e i conservatori». *XV Conferenza del Colore. Colore e Colorimetria. Contributi Multidisciplinari.* Macerata, 5-7 diciembre 2019. Milan: A. Bottoli e V. Marchiafava, pp. 120-127. Avaible in:

https://www.academia.edu/41346665/2019_Riconoscere_dal_colore_Pigmenti_e_coloranti_dellet%C3%A0_moderna_nellanalisi_multibanda_dei_dipinti_uno_strumento_visivo_per_gli_storici_dellarte_e_i_conservatori_in_Colore_e_Colorimetria_Contributi_multidisciplinari_a_cura_di_A_Bottoli_e_V_Marchiafava_pp_120_127

Bomford, D., Dunkerton, J., Gordon, D., & Roy, A. (1995). *La pintura italiana hasta el 1400. Materiales, métodos y procedimientos del arte*. Barcelona: Ed. Serbal.

Cosentino, A. (2015a): «Effects of different binders on technical photography and infrared reflectography of 54 historical pigments». *International Journal of Conservation Science*, 6 (3), pp. 287-298. Available in: https://www.researchgate.net/publication/281651173_Effects_of_different_binders_on_technical_photography_and_infrared_reflectography_of_54_historical_pigments

Cosentino, A. (2015b). Practical notes on ultraviolet technical photography for art examination. *Conservar Património*, (21), 53-62.

Cosentino, A. (2016): «Infrared technical photography for art examination». *e-Preservation Science*, 13, pp. 1-6. Availabe in: http://www.morana-rtd.com/e-preservationscience/2016/ePS_2016_a1_Cosentino.pdf

Díaz Mata, L. (2022). *Veladuras con pigmentos inorgánicos (ss. XV-XVIII). Reconstrucción experimental y caracterización multi-técnica.* Universitat Politècnica de València. http://hdl.handle.net/10251/186375

Dodwell, C. R. (1961). *The Various Arts: (De Diversis Artibus*. Oxford: Clarendon Press.

Fuster López, L., Stols-Witlox, M., & Picollo, M. (Eds.). (2020). *UV-Vis Luminescence imaging techniques/Técnicas de imagen de luminiscencia UV-Vis* (Vol. 1). Editorial Universitat Politècnica de València. http://hdl.handle.net/10251/138517

Gollini, G. (2020) *Potenzialità della tecnica di imaging iperspettrale per lo studio di pitture a olio in presenza di velature*. Master Thesis. Università Degli Studi Firenze.

Herrero-Cortell, M.A; Raïch, M; Artoni, P. *et al*. (2018): "Multi-band technical imaging in the research of the execution of paintings. The case study of the portrait of Carlos IV, by Francisco de Goya". *Ge-Conservación*, 14, pp. 5-15. doi: 10.37558/gec.v14i1.583. Availabe in: https://ge-iic.com/ojs/index.php/revista/article/view/583

Herrero-Cortell, M. Á., Creus, M. R., Artoni, P., & García, J. A. M. (2022). Caracterización de pigmentos históricos a través de técnicas de imagen, en diversas bandas del espectro electromagnético. *Ge-conservacion*, (22), 58-75. Availabe in: https://ge-iic.com/ojs/index.php/revista/article/view/1101/1111

Kühn, H. (1968). Lead-tin yellow. *Studies in Conservation*, 13(1), 7-33. Availabe in: https://www.jstor.org/stable/1505386

Llácer-Peiró, A (2021). *Veladuras históricas con pigmentos laca. Aproximación teórico-práctica y caracterización en diversas bandasdel espectro.* Universitat Politècnica de València. Master Thesis. http://hdl.handle.net/10251/173723

Llácer-Peiró, A; Herrero-Cortell; M.A, Zalbidea-Muñoz, M.A; Fuster-López, L. (2023) Historical glazes: Enhancing their value through reproduction and characterisation. *Color, Culture and Science Journal*, 12, vol. 5, pp. 39-46. Availabe in: https://www.academia.edu/113104923/_2023_Historical_glazes_Enhancing_their_value_through_reproduction_and_characterisation_Color_Culture_and_Science_Journal_12_vol_5_pp_39_46?uc-sb-sw=108684656

Mayer, R. (2005) *Materiales y técnicas del arte*. Madrid: Tursen - H. Blume.

Pereira, J.M. (2018) "25 años del control de calidad en la digitalización de bienes culturales", *Revista PH*, nº 95 especial 25 años, pp. 63-67. Availabe in: file:///Users/arantxa/Downloads/4226-Texto%20del%20art%C3%ADculo-10568-1-10-20181126-3.pdf

Rejón de Silva, D.A. (1748) *El tratado de la pintura por Leonardo de Vinci, y los tres libros que sobre el mismo arte escribió León Bautista Alberti.* Madrid: Imprenta Real.

Salinas, M.F., Hatchondo, F. (2005) "Evaluación del proceso de limpieza del lienzo de Cuauhquechollan a través de mediciones colorimétricas", *Conserva*, 9, pp. 43-58. Availabe in: https://www.academia.edu/3988720/Evaluaci%C3%B3n_del_proceso_de_limpieza_del_lienzo_de_Cuauhquechollan_a_trav%C3%A9s_de_mediciones_colorim%C3%A9tricas

Santos, S. (2005) *Las preparaciones de yeso en la pintura sobre tabla de la escuela española.* PhD Thesis. Madrid: Universidad Complutense de Madrid. https://hdl.handle.net/20.500.14352/56065

Torres, A. (2015) Forma y Color: La grisalla en la pintura; aproximación a un procedimiento inadvertido. *Barcelona, Research, Art Creation, 3(2), 179-200. doi: 10.17583/brac.2015.1350.*

Villarquide, A. (2004) *La pintura sobre tela*. San Sebastián: Nerea.

Zalbidea Muñoz, M. A. (2014). *Els vernissos artístics: Revisió i evolució*. València. Universitat Politènica de València. http://hdl.handle.net/10251/66792

Zalbidea Muñoz, M.A., Giner-Cordero, E (2017) "Pratica di tecniche artistiche storiche. Le vernici di Teofilo", *KERMES Art Conservation Restoration*,30(106), pp.76-77. http://hdl.handle.net/10251/112366

Zalbidea Muñoz, M. A., Zelazowski, J., y Herrero-Cortell, M. (2022) "De diversus artibus, un recetario de tecnología artística para el estudio de los barnices medievales". *1st European Symposium on Drugs & Colors in History*. Tirant Lo Blanch. *In press.*

Optical Characterisation of Oil Painting Films with Drying Pigments under the Microscope: Cobalt Blue

Aránzazu Llácer-Peiró[1], M. Antonia Zalbidea-Muñoz[2], Miquel Àngel Herrero-Cortell[3], Laura Fuster-López[1]

[1] *Instituto Universitario de Restauración del Patrimonio, UPV*

[2] *Departamento de Conservación y Restauración de Bienes Culturales, UPV*

[3] *Departamento de Comunicación Audiovisual, Documentación e Historia del Arte, UPV*

Corresponding author: Aránzazu Llácer-Peiró, arllapei@cap.upv.es

ABSTRACT

Traditionally, oil painting techniques have used certain additives to improve and adjust the rheological characteristics and properties of oil paints. In addition to the main components of oil paints, such as pigments and oils, additives have been used, among which driers, mainly composed of metallic salts such as lead, zinc, cobalt, manganese, copper or iron, play a crucial role in accelerating the drying process of the paint.

This paper focuses on the study of oil paint films made with cobalt blue pigment. The main objective is to observe and characterise this pigment using various non-invasive techniques. Specifically, it focuses on the microscopic observation of mock-ups made with cobalt blue in order to detect possible changes in the morphology of different pigments caused by accelerated ageing. This article aims to complement the characterisation of these mock-ups by colorimetry, the results of which were presented at the XVIII Conferenza del Colore in Lecco, 2023 (Llácer Peiró et al., 2023).

KEYWORDS drying pigments, cobalt blue, surface microscopy, artificial ageing

RECEIVED 01/08/2024; **REVISED** 23/10/2024; **ACCEPTED** 04/11/2024

1. Introduction

Oil painting is characterised by being a technique that employs ground pigments and/or dyes bound in a drying oil. The technique of oil painting is closely related to the use of additives to accelerate the drying process. The effectiveness of drying agents depends on the quality, purity, and application of the materials used (Zumbühl and Zindel, 2022). Although compared to other mediums, drying oils facilitated the rapid drying of paint, allowing artists to work more quickly (Eastlake, 1847; Laurie, 1926), at times the drying time was not fast enough, especially when working with multiple layers of paint. For this reason, other additives were incorporated as catalysts to further accelerate the drying process (San Andrés et al., 1996). Drying materials commonly used in oil painting include:

- Binders, typically oxidative drying oils. These are the drying oils mentioned above (linseed, walnut, or poppyseed oil) (San Andrés et al., 1996; Matteini and Moles, 2001).
- The pigments themselves, especially those of metallic nature, such as litharge or lead white. These metals act as driers by accelerating the drying process, reducing the induction period, increasing the formation and breakdown of peroxide, and finally polymerisation (Girard et al., 1965; Honzíček, 2019; Bieleman, 2002).
- Metallic salts, added to the oil as liquid driers to catalyse drying, such as Cobalt siccative, Harlem siccative, or Courtrai siccative (Villarquide, 2004).
- Natural (mastique, rosin) or synthetic (alkyd) resins, substances widely used as drying agents (Armenini, 1587; Eastlake, 1847; Merrifield, 1849; Doerner, 1998).

Although there was empirical knowledge of how certain materials affected the drying of paints, detailed studies of drying agents did not appear until the 1840s, when zinc oxide began to replace lead white (Bieleman and Lomölder, 2000). Analysing how these pigments can affect alteration, deterioration or pathology in a work is crucial for accurate diagnosis. The identification of these pigments can serve as a starting point for the characterisation of the artwork. This paper focuses on the study of oil paint films containing cobalt blue pigments, both as single paint films (without ground layer) and in interaction with the underlying ground layer. Specifically, it presents the microscopic analysis carried out to detect possible morphological changes caused by accelerated artificial ageing. This study complements the colorimetric analysis of these pigments, the results of which were presented at the XVIII Conferenza del Colore in Lecco (Llácer Peiró et al., 2023). The data and conclusions derived from this study may contribute to the understanding of the role of cobalt pigments in the modification and/or alteration of oil paintings. In addition, these results could be compared withcase studies to identify possible similarities and differences.

2. Objectives

The main objective of the present study is to identify and investigate the morphological changes that can occur in the paint film as a result of artificial ageing processes using a xenon lamp. Specifically, the study will investigate to what extent the use of cobalt blue pigments either on a traditional chalk-based ground layer and on an inert surface (glass), combined with different drying oils (linseed oil or walnut oil), can influence these phenomena. In this way, a deeper understanding is sought of how these aspects can contribute to the dimensional variations observed.

3. Materials and methods

3.1. Mock-ups Preparation

Three types of cobalt blue pigments (Kremer Pigmente) were used for characterisation: medium cobalt blue, dark cobalt blue, and cerulean blue, manually bound with two drying oils (linseed oil and cold-pressed walnut oil) (Table 1). Sources consulted on the appropriate proportions for binding oil and pigment showed discrepancies (Mayer, 1993; Myers, 2013). For this reason, the measures provided by Kremer Pigmente were followed to achieve the optimal quantitative ratio between pigment and binder (known as Critical Pigment Volume Concentration - CPVC-) [1] (Table 2).

Table 1. Materials used in the experimental

Pigment	*Ref. Kremer*	*Color Index*			*Chemical formulation*	
Cobalt cerulean blue	45730	PB 35. C.I. 77368			$CoO\text{-}nSnO_2$	
Cobalt blue medium	45710	PB 28. C.I. 77346			$CoAl_2O_4$	
Cobalt blue dark	45700	PB 74. C.I. 77366			$(Co,Zn)_2SiO_4$	
	Ref. Kremer	**Fatty acid composition (%)** (*Izzo, 2011*)				
Binder		**Palmitic**	**Stearic**	**Oleic**	**Linoleic**	**Linolenic**
Linseed oil, cold-pressed	45730	4-10	2-8	10-24	12-19	48-60
Walnut oil, cold-pressed	45710	3-8	0,5-3	9-30	57-76	2-16

Table 1. Ratio of pigments and binders.

Table 2. Proportions of pigment binder used

Pigment	*Linseed oil ratio*	*Walnut oil ratio*	*Pigment ratio*
Cobalt cerulean blue	16,67%	16,67%	83,3%
Cobalt blue medium	27.01%	27.01%	72.99%
Cobalt blue dark	15.25%	15.25%	84.75%

Table 2. Proportion of binder/pigments used in the preparation of the mock-ups.

The mixtures obtained were applied to two types of support: on wood (Medium Density Fiberboard, MDF) boards, measuring 2.5 x 8 cm, prepared with a chalk ground made of sulphate, calcium carbonate and animal glue (Santos, 2005); and on glass slides, measuring 2.5 x 7.5 mm (Figure 1). Both materials are dimensionally stable. The glass allowed for the evaluation of the interaction between the pigment and the oil, avoiding interferences with other ground layers. The MDF board was used to observe the interaction between the pigment and the ground layer. This choice of a rigid support was aimed to prevent the usual dimensional changes observed in canvases. These mock-ups were prepared under constant environmental conditions of relative humidity (RH) of 49% and temperature (T ºC) of 20 ºC.

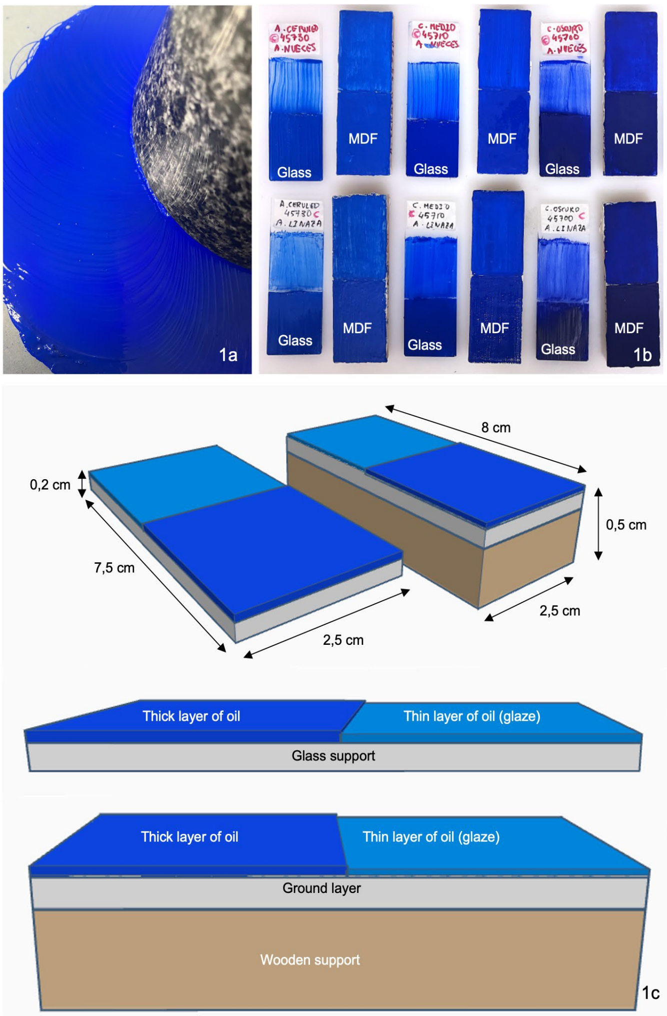


Fig. 1. Grinding cobalt blue pigment in linseed oil (1a), mock-ups made on the two substrates (1b), and diagrams of the different substrates used in this study (1c).

3.2. Artificial ageing

The mock-ups were subjected to ageing under artificial light provided by a xenon lamp (Suntest CPS+ Atlas) to evaluate changes in their properties caused by sunlight and temperature. This phase was carried out according to the ASTM D4303-03 standard, supported by previous research on the ageing of artistic materials (Sánchez and Micó, 2010; De los Reyes et al., 2015; López-Montes et al., 2016; Cavaleri et al., 2019). The specific process conditions were as follows:

- Filter: Window glass red. IR
- Wavelength (nm): 300-800 nm
- Irradiance (W/m^2): 500
- Temperature BST: 50º
- Chamber air temperature: 34º
- Duration time (h): 250+250 = 500 Total

In Figure 2, images of the mock-ups before and after artificial ageing are shown.

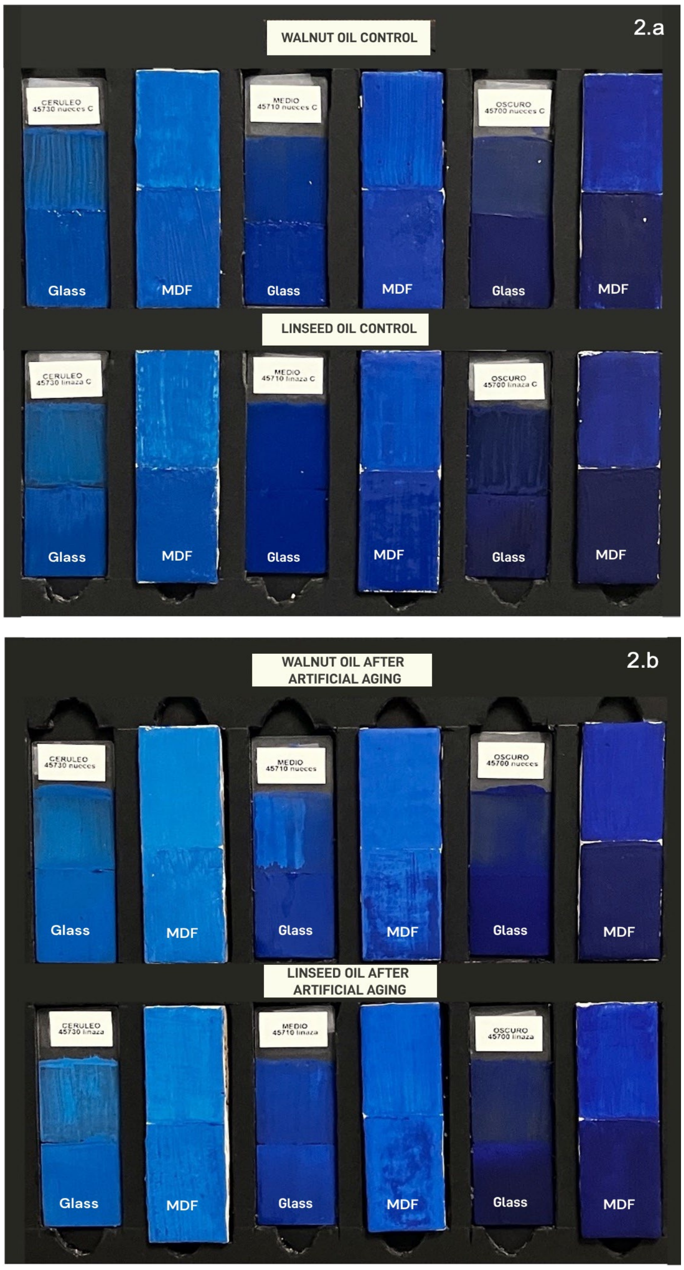


Fig. 2. 2a: Mock-ups before accelerated ageing; 2b: Mock-ups after ageing

.3.3. Microscopy

Stereomicroscopy is a technique that allows precise observation and characterisation of materials, allowing morphological studies through visual analysis of particle size, dispersion or distribution of pigment particles. The study used the stereomicroscope Leica® MZ APO and Leica® M165 120x. Representative areas were selected and sampled in all mock-ups (Figure 3) in order to obtain maximum information about the changes in the paint film. To facilitate the interpretation of the results, Table 3 shows the abbreviations used to identify the mock-ups, including the type of substrate, binding media, sampling area and pigment used.

Table 3. Acronyms used to identify mock-ups

Support	Binder	Zone	Pigment
W= wood G= glass	LI= linseed NU=walnut	Z	Cerulean Medium Dark

Table 3. Acronyms used for mock-ups identification

In this way, the image named "W-LI-Z1-Cerulean 1" corresponds to microscopy performed on the board support (W), with linseed oil as binding media (LI), in sampling area 1 (Z), using cerulean blue pigment.

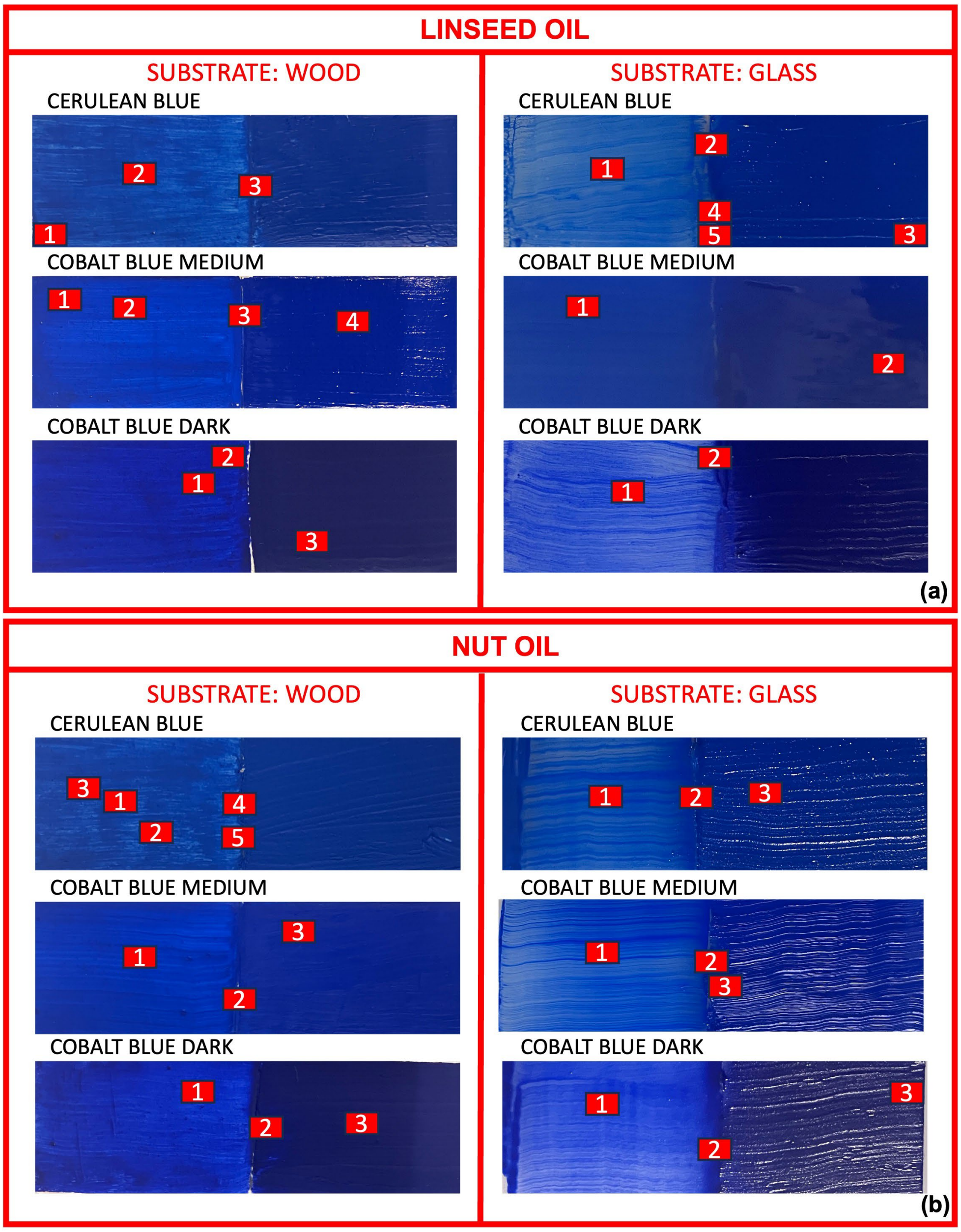


Fig. 3. Location of the sampling points where microscopy was performed: mock-ups with linseed oil (a) and with walnut oil (b).

4. Results

After subjecting the mock-ups to artificial ageing, widespread loss of the initial brushstrokes was observed in most of the mock-ups on wooden supports. This loss is attributed to the levelling index of the binder. When a brushstroke is applied, the viscosity of the binder decreases, improving its flowability. When the binder rests, it returns to its original viscosity, causing surface levelling (Zalbidea, 2014; Alonso Felipe, 2016). The porous nature of wood allows it to absorb some of the binder. Conversely, the non-porous nature of glass prevents the paint from penetrating the substrate, resulting in more defined brushstrokes and preserving some of the texture created by the brush.

4.1. Cerulean Blue

After applying the pigment to the wood panel using both oils, a smooth and homogeneous surface with a velvety appearance is observed. The pigment plus binder mixture has a medium tinting strength and, as it can be observed in the pictures, it is the only cobalt blue pigment without a violet hue [2] (Gettens & Stout, 1966).

- Results on the wooden panel: after 250 hours of accelerated ageing, the mock-ups show a more heterogeneous appearance due to the presence of spots and small craters on the surface of the paint layer caused by air entrapment. After 500 hours, the surface becomes rougher with persistent spots (Figures 4D, 4E, 4F). After 250 hours of accelerated ageing, the binder in the paint remains visible on the surface (Figure 4B). However, after 500 hours, the binder is not visually perceptible, resulting in the formation of small cavities or holes in the paint surface (Figure 4C). After 500 h, a surface fracture is observed in the areas of intersection between the thick brushstrokes and those applied as a glaze (Figure 4I). This phenomenon had not manifested prior to the artificial ageing process (Figure 4G). No significant morphological differences are observed between the two types of oil used.

- Results on the glass slide: a finer, more uniform and less opaque surface is produced on the glass support. This phenomenon is attributed to the refractive index of glass (1.5), which is very similar to the refractive index of both oils (1.484 for linseed oil and 1.46 for walnut oil) (Knut, 1999), resulting in a more translucent appearance compared to the wooden support (Figures 4P and 4R). After ageing, irregularly distributed dark spots are observed on the surface. These spots, which are rounded in shape and vary in size (Figure 4Q), are caused by pigment accumulation. No significant morphological differences were observed between the two types of oil used.

4.2. Medium Cobalt Blue

The medium cobalt blue has a more purplish hue than cerulean blue [3]. As described by Roy (2007), it has a cloudy and powdery appearance. Like cerulean blue, the surface is initially homogeneous and uniform, a characteristic that changes after ageing and acquires a more irregular texture (Figures 5C and 5I).

As the refractive index of medium cobalt blue (1.74) is lower than that of cerulean blue (1.84) (Knut, 1999), the former becomes a less opaque pigment (Figures 5K and 5L). It is important to distinguish between 'hiding power' and 'opacity'. Although these terms are closely related and are often used interchangeably, they have different nuances in technical meaning. Opacity refers to the ability of the pigment to hide the colour of the substrate to which it is applied, whereas hiding power refers to the ability of the pigment to block the passage of light through it. Opacity is closely related to refractive index, and opacity is proportional to the difference between the refractive index of the pigment and that of the binder in which it is dispersed (Abel, 1999; Doménech, 2020).

- Results on the wooden panel: in mock-ups where the pigment is bound with walnut oil, voids caused by air retention are visible on the surface (Figures 5G-5I). Around these voids, early shrinkage cracks formed without reaching the primer layer. These cracks occur as the surface layer of paint dries (Knut, 1999). The role of cobalt as a drying agent may contribute to the formation of these surface cracks (Soucek et al., 2012; Fuster-López et al., 2019).

Figures 5E and 5F show that in areas where a thin layer of pigment has been applied there are no dark spots caused by the binder after 500 hours of ageing. The reason is the thickness of the applied film, another factor that influences the oxidation process of the oil. Thicker paint films require longer drying times (Mallégol et al., 2000).

- Results on the glass slide: brushstrokes are visible, but unlike cerulean blue on glass, there are no dark spots due to pigment accumulation (Figures 5O-5Q), probably because of the small particle size (between 2 and 40 μm) compared with that of cerulean blue (Roy, 2007).

4.3. Dark Cobalt Blue

- Results on the wooden panel: with regard to the dark cobalt pigment applied to the wood panel, the surface shows a relatively uniform distribution of pigment with some areas showing greater clustering, an effect that persists after 500 hours of ageing (Figures 6A, 6B and 6C). Small scattered dark spots are evident, which may indicate areas of pigment accumulation.

Cratering can be seen in Figures 6D, 6E and 6F, an effect noted by Damato (2014). Bright white spots can be seen in some mock-ups (Figures 6F, 6I and 6L). In future studies, elemental analysis using SEM-EDX will be performed to obtain further information on these mock-ups. It can be observed that before the mock-ups are subjected to the ageing process, cratering has already occurred, surrounded by a brighter and diffuse halo, although they do not have cracks around their perimeter (Figures 6D, 6E and 6F). This pattern persists even after 500 hours of ageing.

In some areas of the mock-up prepared with dark cobalt pigment and walnut oil, the surface is extremely rough with numerous irregularities, as shown in Figures 6J, 6K and 6L.

- Results on the glass slide: after 500 hours of ageing, a reduction in the opacity of the paint is observed, even in areas where thicker layers have been applied (Figures 6Ñ and 6Q). This decrease in opacity is attributed to the similarity between the refractive indices of glass and the oils used as binders (Knut, 1999). Because the refractive index of glass is close to that of the oils, light passes more directly through the material, reducing the paint opacity.

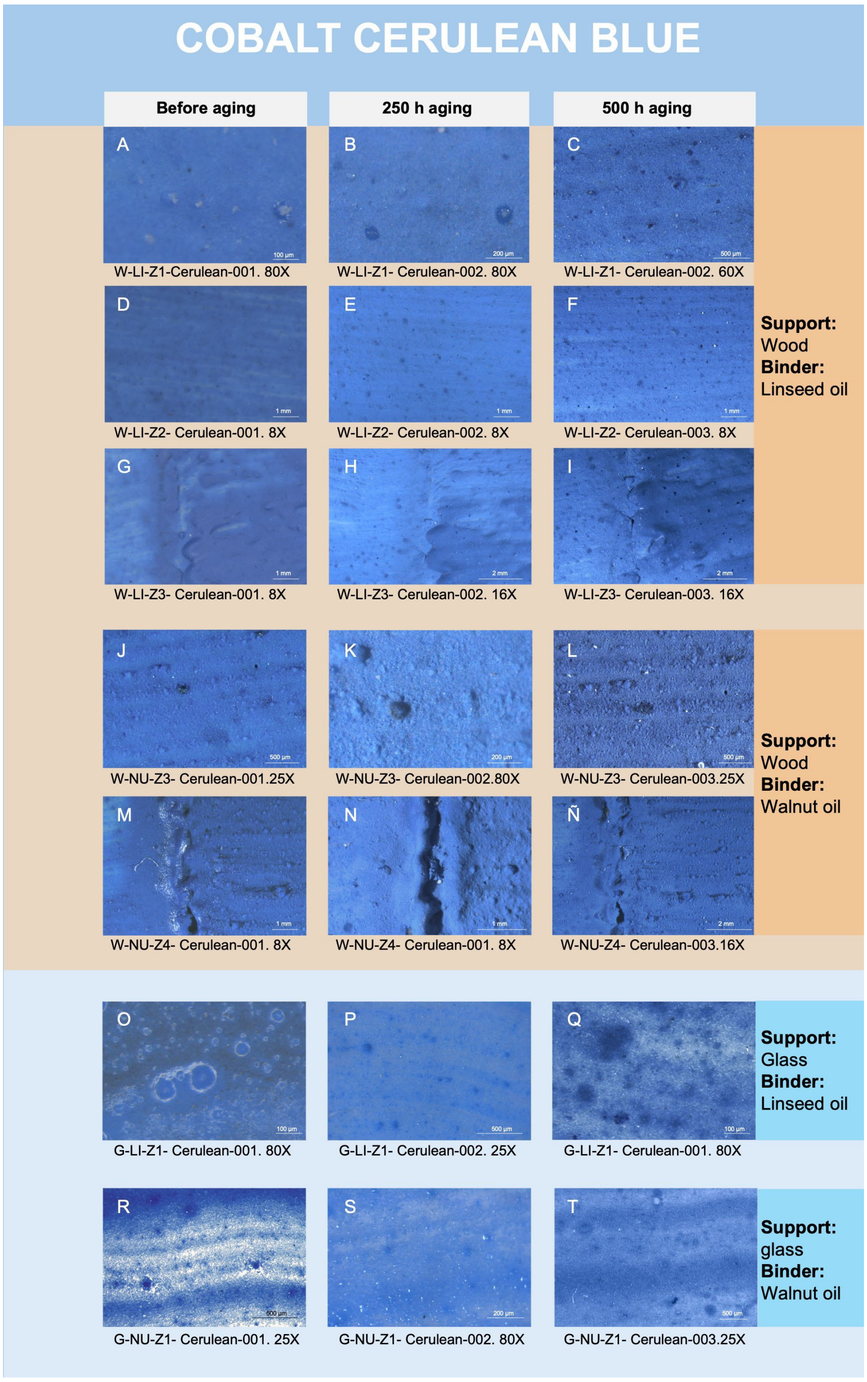


Fig. 4. Microscopic images of cerulean blue pigment bound with linseed oil and walnut oil and applied on MDF board and glass.

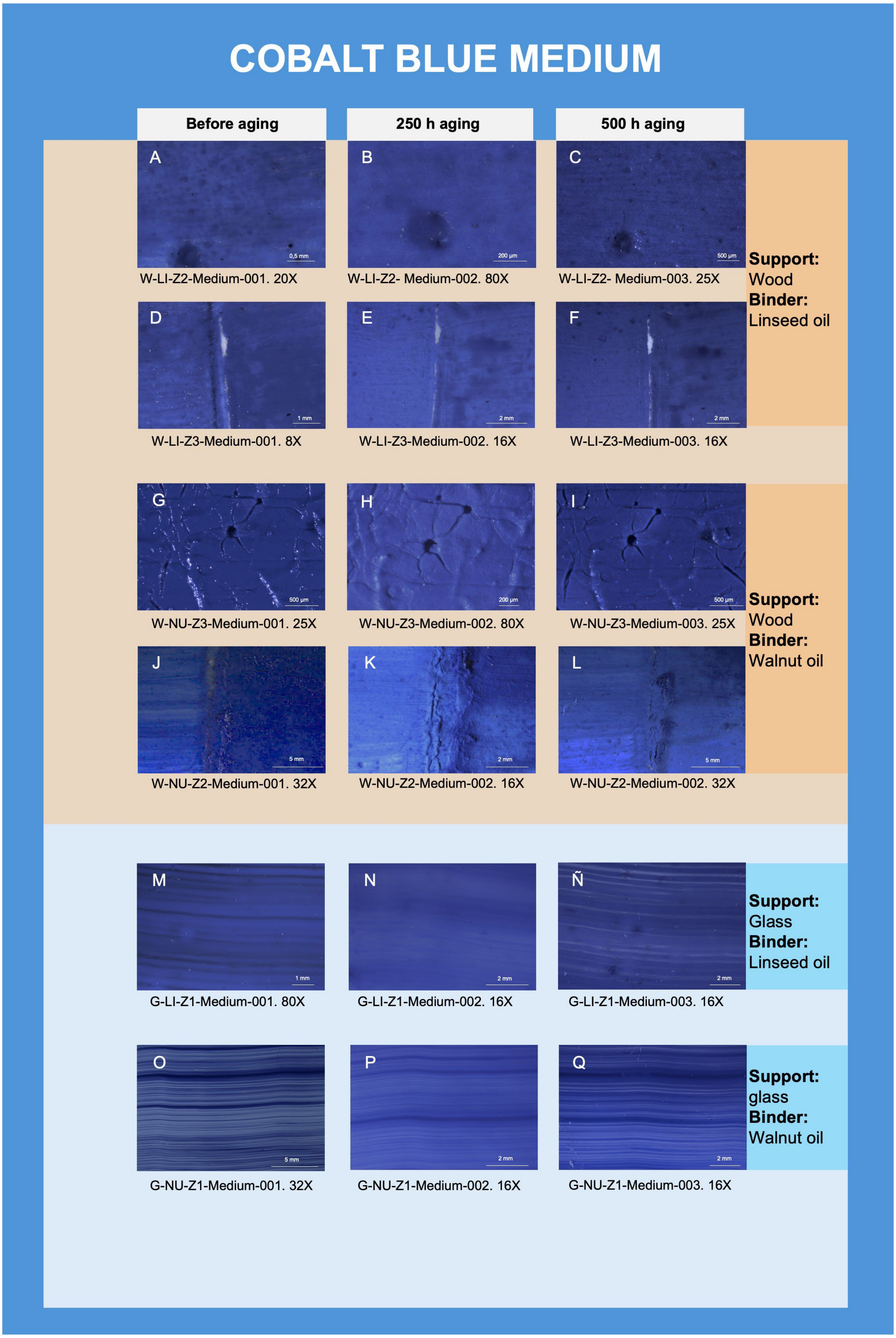


Fig. 5. Microscopic images of cobalt blue medium pigment bound with linseed oil and walnut oil and applied on MDF board and glass.

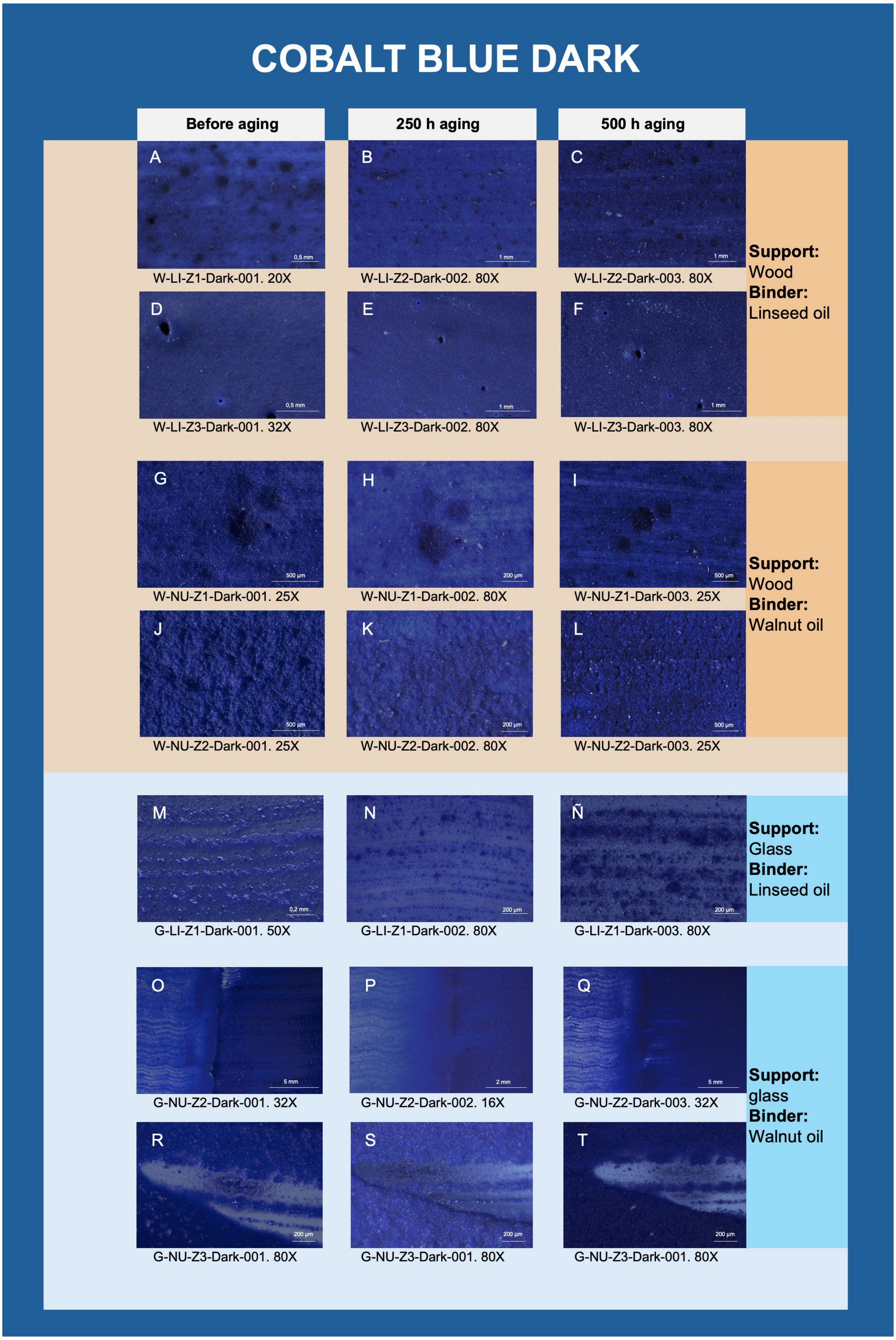


Fig. 6. Microscopic images of cobalt blue dark pigment bound with linseed oil and walnut oil and applied on MDF board and on glass.

5. Conclusions

This paper presents an experimental study for the characterisation of oil paint films containing cobalt blue, cerulean blue, and dark cobalt blue pigments using optical microscopy. Particular attention was paid to morphological and optical changes induced by accelerated artificial ageing in mock-ups prepared on different supports.

Cobalt belongs to the category of primary or active driers (along with manganese and lead, among others). They act as oxidation catalysts and cause surface drying. However, their role as driers can contribute to the formation of surface cracks.

Examination of the mock-ups by stereoscopic microscopy revealed significant changes in the structure and appearance of the oil paint films with all three cobalt pigments after accelerated ageing.

With regard to the support used, the nature of the support directly influences the morphology of the oil paint film and affects its dimensional variations. The ground layer applied on the MDF board absorbs part of the binder, resulting in a loss of brushstroke definition and increased opacity of the paint layer. In contrast, non-porous glass retains sharper brushstrokes but has less natural adhesion, resulting in surfaces with less pigment accumulation.

After artificial ageing, it was observed that mock-ups prepared on glass tended to retain a more uniform and less opaque surface due to the similarity in refractive indices between glass and the oils. Mock-ups prepared on wood, on the other hand, developed a rougher surface.

The presence of pigment aggregates was observed in all the mock-ups prepared on wood support, due to the roughness of the ground layer surface, which allows pigment particles to settle in the depressions. This resulted in a less uniform pigment distribution and affected the surface morphology. No significant difference was observed between the two types of binder used.

Brushstroke thickness also influenced the morphological changes of the oil paint film. Areas with thicker brushstrokes showed the presence of dark spots of heterogeneous sizes and shapes. The thickness of the paint layer affects the oil oxidation process. Thicker layers increase the drying time. This factor, combined with the superficial drying property of cobalt, results in an inefficient drying depth, slowing oxygen diffusion within the film volume.

After artificial ageing, a decrease in opacity was observed in the samples, attributed to a change in the refractive index of the binders.

The results obtained through microscopy and colorimetry (Llácer Peiró et al., 2023) allow for a better interpretation of the data, offering a more comprehensive view of the observed effects. The colorimetry data indicated that ageing affects the mock-ups differently depending on the support used In the samples made on MDF board, an increase in saturation was observed after ageing, while the opposite trend was noted with glass mock-ups (Llácer Peiró et al., 2023). This effect is confirmed at the microscopic level. It is due to the porosity of the ground layer on the MDF board, which facilitates greater pigment accumulation, potentially increasing saturation, while the uniformity of the film on the glass could explain the decrease in saturation.

This study has provided a more detailed understanding of the morphological changes caused by ageing in oil paint films containing cobalt blue pigment. These findings can provide valuable insights for the evaluation and study of artworks in which this pigment is used, as well as for the development of diagnostic strategies.

6. Conflict of interest declaration

The authors wish to state that no financial or personal interests have affected the objectivity of the study, and that no conflicts of interest exist.

7. Funding source declaration

This research has been carried out within the framework of the PID 2019-106616ES-100 project awarded by MCIN/AEI /10.13039/501100011033. The authors acknowledge the access to the Microscopy Services of Universitat Politècnica de València (UPV), and to the Central Support Service for Experimental Research of Universitat de València - SCSIE (UV).

8. Short biography of the author(s)

Aránzazu Llácer-Peiró - Research Technician pursuing the PhD in Conservation at Instituto Universitario de Restauración del Patrimonio (Universitat Politècnica de València) on the study of drying pigments through a multi-analytical approach.

Mª Antonia Zalbidea-Muñoz - Professor in the Department of Conservation and Restoration of Cultural Heritage at the UPV, field in which she holds a doctorate degree. She has directed her research on the procedural, material and conservative aspects of mural painting, as well as parts related to varnishes and dyes in painting. At present she is also a collaborator in the work team of the project: Byzantine illuminated manuscripts in Spain: work, context and materiality - MABILUS (MICINN-PID2020-120067GB-I00).

Miquel Àngel Herrero-Cortell - He holds a PhD in Art History. He has a degree in Fine Arts from the Polytechnic University of Valencia (UPV) and a degree in Art History from the University of Valencia (UV). He holds a Master's Degree in Conservation and Restoration of Cultural Heritage and a Master's Degree in Artistic Production. He has developed his work as a researcher focusing on the field of materials and painting techniques, as well as on painting diagnosis. He is currently teaching at the Universitat Politécnica de València.

Laura Fuster-López - Professor at the Conservation Department of the Universitat Politècnica de València (Spain). After several research fellowships in Europe and the United States, she obtained her PhD in Conservation at the UPV, where since 2007 she has been coordinating the area dedicated to the study of the mechanical and dimensional properties of cultural materials. She has been involved in numerous international R&D projects, always with a particular focus on understanding the mechanisms involved in the behaviour and degradation of paintings.

Notes

[1] The uniformity of a paint film depends on several factors, such as the grinding of the pigments and the absorption and wetting properties of the binder. When these materials are mixed, the binder first coats the paint particles (binder absorption) and then the air fills the spaces between the particles, becoming impregnated with the binder (interstitial binder). These two stages are essential to achieve a compact and uniform film (Zalbidea, 2014).

[2] The colorimetric data obtained from the samples, the results of which were presented at the XVIII Conferenza del Colore in Lecco, 2023 (Llácer Peiró et al., 2023), indicate the following values for cerulean blue: L*= 36.10; a*= -1.58; b*= -39.53; C* = 39.56; H* = 267.73, confirming that this pigment does not have a violet hue, as stated by Gettens & Stout.

[3] The colorimetry data from samples shows the following results for medium cobalt blue: L*= 29,84; a*= 10,51; b*= -45,94; C* = 47,13; H* = 282,91.

Licensing terms

References

Abel, A.G. (1999) Pigments for Paint. In: Paint and Surface Coatings. R. Lambourne and T. A Strivens, Cambridge: Woodhead Publishing Limited, 91-165. https://doi.org/10.1533/9781855737006.91.

Armenini, G. B. (1999) De los verdaderos preceptos de la pintura (1586/7), intr. y not. M.C. Bernárdez Sanchís. Madrid: Visor Libros.

Alonso Felipe, Jose Vicente. (2016). Pinturas, barnices y afines: composición, formulación y caracterización. Madrid: E.T.S.I. Industriales (UPM).

Bieleman, J. and Lomölder, R. (2000) "Catalytically Active Additives". In: Additives for Coatings. Ed. by Bieleman, J. Weinheim: Wiley-VCH, pp. 201-256. DOI:10.2533/000942902777680568.

Bieleman, J. H. (2002). Driers. CHIMIA International Journal for Chemistry 56 (5):184–90. DOI: 10.2533/000942902777680568.

Cavaleri, T., Fiocco, G., Rovetta, T., Dondi. P., Malagodi. M., Gulmini, M., Piccirillo, A., Pisani, M., Zucco, M. y Gargano, M. (2019) "Un nuevo método de imagen de luminiscencia inducida por UV multiespectral para el estudio de recubrimientos en instrumentos musicales históricos". En: Picollo, M., Stols-Witlox, M., Fuster-López, L. eds. Técnicas de imagen de luminiscencia UV-Vis. Valencia: Universitat Politècnica de València. DOI: https://doi.org/10.4995/360.2019.110002

Damato, C. (2014). Pitture commerciali a base di Blu di Cobalto: studio delle propietà chimiche, fisiche e meccaniche, atto alla comprensione del loro potenziale degrado ed alle conseguenti implicazioni nella loro conservazione. Doctoral thesis. Venice: Università Ca' Foscari Venezia.

De los Reyes, F., De los Reyes, B. Plaza, M. (2015) "Los pigmentos tradicionales en el arte contemporáneo: el caso del azul esmalte", 16ª Jornada Conservación de Arte Contemporáneo. Madrid, febrero 2015. Madrid: Museo Nacional de Arte Reina Sofía, pp. 117-128.

Doerner, M. (1998): Los materiales de pintura y su empleo en el arte, 6ª. ed. Barcelona: Reverté.

Doménech Carbó, M. T. (2020) Principios físico-químicos de los materiales integrantes de los bienes culturales. Valencia: Universidad Politécnica de Valencia.

Eastlake, C. (1847) Materials for a History of Oil Painting. Vol 1. London: Brown, Green and Longmans.

Fuster-López, L., F.C. Izzo, V. Damato, D.J. Yusà-Marco, and E. Zendri (2019) An insight into the mechanical properties of selected commercial oil and alkyd paint films containing cobalt blue. Journal of Cultural Heritage, 35, 225–234.

Gettens, R., Stout, G. (1966) Painting materials: A short encyclopaedia. New York: Dover.

Girard, T.A., Beispiel, M. & Bricker, C.E. (1965). The mechanism of cobalt drier action. J Am Oil Chem Soc 42, 828–833 https://doi.org/10.1007/BF02541168

Gottsegen, M. D. (2006) The painter's handbook. New York: Watson-Guptill.

Honzíček, J. (2019). Curing of Air-Drying Paints: A Critical Review. Industrial & Engineering Chemistry Research, 58(28), 12485– 12505, DOI: 10.1021/acs.iecr.9b02567

Izzo, F.C. (2011) 20th Century Artists' Oil Paints: A Chemical-Physical Survey. Doctoral Thesis in Chemical Sciences. Venice: Università Ca' Foscari Venezia

Knut, N. (1999) Manual de restauración de cuadros. Köln: Könemann.

Laurie, A.P. (1926) The Painter's Methods and Materials. London: Dover.

Llácer-Peiró, A., Zalbidea-Muñoz, M.À., Herrero-Cortell, M.A. and Fuster-López. L. (2023). Caratterizzazione ottica di pellicole pittoriche a olio con pigmenti essiccanti: blu cobalto. In: Colore e Colorimetria Contributi Multidisciplinari, XVIII Conferenza del Colore. Lecco, 15-16 september 2023. Milan: Gruppo del Colore, 63-72. https://flore.unifi.it/retrieve/30850ad9-7c85-448a-995d-837f65b15c8d/Proceedings_CdC2023_ITA-VolXVIIIB_spennato.pdf

López-Montes, A., Laurence, A., Tello, N., Espejo, T., Blanc, R. (2016) “Identificación de materiales colorantes tras un proceso de envejecimiento artificial”. Óptica Pura y Aplicada, 49 (3), pp. 143-153. DOI: 10.7149/OPA.49.3.49006

Mallégol, J.; Gonon, L.; Lemaire, J.; Gardette, J.L. (2001) Long-term behaviour of oil-based varnishes and paints 4. Influence of filmthickness on the photooxidation. Polymer Degradation and stability, 72, 191–197. https://doi.org/10.1016/S0141-3910(00)00170-1.

Matteini, M., Moles, A. (2001) La química en la restauración: los materiales del arte pictórico. San Sebastián: Nerea.

Mayer, R. (1993): Materiales y técnicas del arte, 2ª ed. Madrid: Tursen/Hermann Blume.

Merrifield, M.P. (1849) Original Treatises, Dating from the XIIth to the XVIIIth Centuries, [o]n the Arts of Painting. London: John Murray.

Myers, D. (2013) Art is Creation. Available in: https://www.artiscreation.com/contact.html [Consulted 15-06-2023].

Roy, A. (2007) Cobalt Blue. En: Artists’ Pigments. A Handbook of their History and Characteristics Vol.4. Ed. by. Berrie, B. H. London: Archetype Publications, pp. 151–178.

San Andrés, M., Barba, C., Báez, M.I., Baldonedo, J.L y Santos, S. (1996) “Los secativos en la pintura: materiales utilizados. Posibilidades de su estudio por microscopia electrónica de transmisión”, XI Congreso de Conservación y Restauración de Bienes Culturales. Castellón, 3-6 octubre 1995. Castellón: Diputación Provincial de Castellón, pp, 67-76.

Sánchez, A., Micó, S. (2010) “Colores comerciales para retoque pictórico de lagunas en restauración de patrimonio: evaluación de diferencias de color y cambios de solubilidad después de procesos de envejecimiento acelerado”, IX Congreso Nacional de Color. Alicante, 1-2 junio 20210. Alicante: Universidad de Alicante, pp. 132-135.

Santos, S. (2005) Las preparaciones de yeso en la pintura sobre tabla de la escuela española. Tesis doctoral. Madrid: Universidad Complutense de Madrid.

Soucek, M.D., Khattab, T., Wu, J. (2012) Review of autoxidation and driers. Progress in Organic Coatings, 73 (4), 435—454. https://doi.org/10.1016/j.porgcoat.2011.08.021.

Villarquide, A. (2004) La pintura sobre tela Vol.I Historiografía, técnicas y materiales. San Sebastián: Nerea.

Zumbühl, S. and Zindel, C. (2022) Historical Siccatives for Oil Paint and Varnishes - The Use of Lead Oxide, Alum, White Vitriol, Pumice, BoneAsh and Venetian Glass as Driers: Historical Written Sources-Production and Raw Material Quality - Technological Significance. Bern: HDW Publications.

Zalbidea Muñoz, M. A. (2014) Els vernissos artístics: revisió i evolució. Valencia: Universitat Politècnica de València. http://hdl.handle.net/10251/66792

The chromatic intervention as a strategy for the revaluation of facades in peri-urban areas. The case of the historic center of Ixtapa, Jalisco, Mexico.

Jimena Vanina Odetti[1], Alberto Reyes González[2], Andrés Enrique Reyes González[3], Fernando Daniel Valdez Olmos[4]

[1] *Department of Architecture, National Technological Institute of Mexico,/ José Mario Molina Pasquel y Henríquez Technological Institute., Puerto Vallarta, Jalisco, México. jimena.odetti@vallarta.tecmm.edu.mx*

[2] *Department of Architecture, National Technological Institute of Mexico,/ José Mario Molina Pasquel y Henríquez Technological Institute., Puerto Vallarta, Jalisco, México. alberto.reyes@vallarta.tecmm.edu.mx*

[3] Department of B*usiness Management, National Technological Institute of Mexico,/ José Mario Molina Pasquel y Henríquez Technological Institute., Puerto Vallarta, Jalisco, México. andres.reyes@vallarta.tecmm.edu.mx*

[4] *Department of Architecture, National Technological Institute of Mexico,/ José Mario Molina Pasquel y Henríquez Technological Institute., Puerto Vallarta, Jalisco, México. fernando.valdez@vallarta.tecmm.edu.mx*

Corresponding author: Jimena Vanina Odetti (jimena.odetti@vallarta.tecmm.edu.mx)

ABSTRACT

The article presents a case study in which urban color is taken as a protagonist element in the realization of a chromatic and artistic intervention for the preservation and/or recovery of the cultural identity of the selected area. The objective was to develop strategies of chromatic intervention in facades that allow the future empowerment and recognition of the identified areas, rescuing their own identity, legible and memorable, and betting on the identity definition in the collective imaginary through color, which is considered one of the strongest and most effective tools, of high value in the change of image and at the same time economic for the revaluation of the chosen areas. The approach contemplated the management and linkage with different sectors of the community (university, neighborhood councils, artistic collectives, businesses and municipal government) to define strategic instruments for chromatic intervention on the facades of a street in the historic center of Ixtapa, Jalisco, Mexico. To this end, participatory chromatic design proposals were contemplated, involving academics, students, neighbors, artists, businessmen and personalities representing the invited government sectors. As conclusions and findings, the article highlights the importance of studying and generating projects around urban color from a perspective that includes it as a symbolic element and protagonist in the shaping of cultural identity in the city. Emphasis is placed on how, when applied to selected architectural typologies, the chromatic design provides a clear syntactic reading, shaping in the collective imagination a system of memorable places as a product of an urban cultural construction. It also stands out that, in the case study presented, color and mural painting became starting points to improve the quality of life of the actors involved and contribute to the development and urban cultural construction of the locality.

KEYWORDS Chromatic Intervention, Urban Color, Architecture and Color, Urban Art and Color. Color and Cultural Identity.

RECEIVED 30/06/2024; **REVISED** 20/09/2024; **ACCEPTED** 04/11/2024

1. Introduction

Among all the senses, visual perception plays an essential role in the perception of urban space, and color is the most attractive part of it. (Dabbagh, 2019)

The chromatic study of a city, then, addresses the construction and perception of its colors as elements that make it unique and relate it directly to its cultural and historical heritage. This perception contributes to the reconstruction of a sense of belonging and local identity, but at the same time reflects the multiplicity of its inhabitants and the elements of the collective culture. (Odetti, 2019)

This document presents a case study on the chromatic and artistic intervention of facades in the center of the town of Ixtapa, which belongs to Puerto Vallarta, Jalisco, Mexico. This intervention was carried out on two block faces of one of the emblematic streets of the area.

Figure 1 shows the location of the intervention area in the center of the town of Ixtapa.

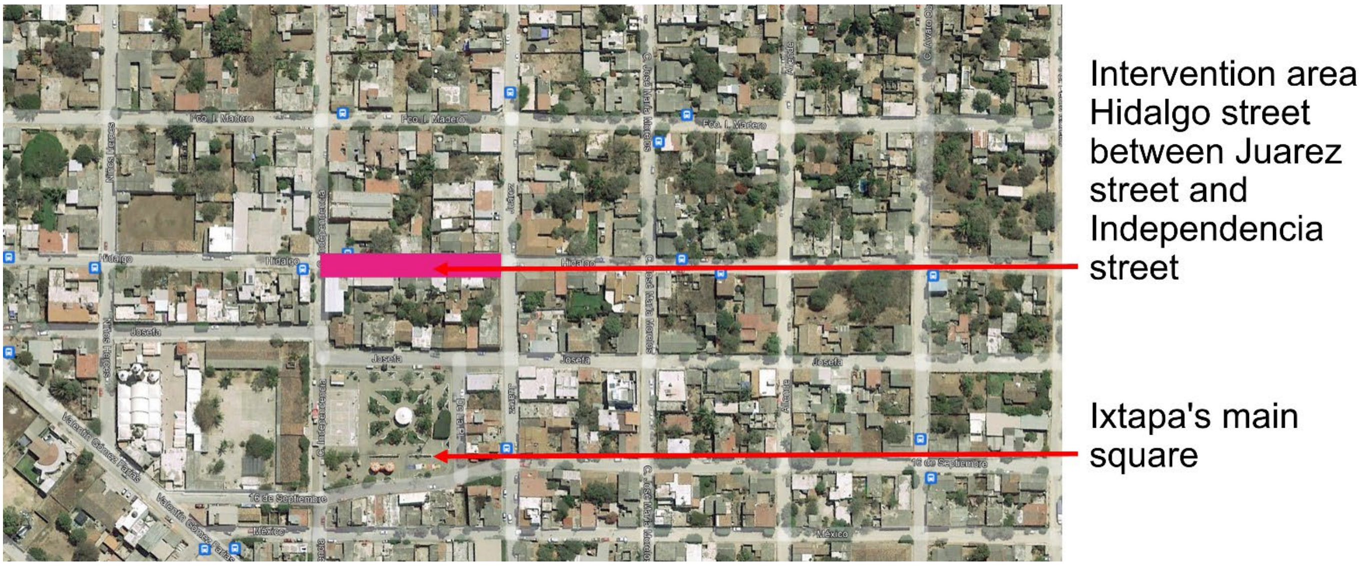


Fig. 1. Location of the intervention area

In the case of a town like Ixtapa, which is linked to an international tourist destination like Puerto Vallarta, the chromatic perception constructed by visitors is added as a variable; therefore, the color of a city with these characteristics is a reflection of the time lived and of the relationships established between inhabitants and visitors, from its past and projection towards the future.

The town of Ixtapa, Jalisco, belongs to the municipality of Puerto Vallarta. It has a population of 39,083 inhabitants (IIEG, 2023) and is 41 meters above sea level. It is a town with a nearby beach: the beaches of Puerto Vallarta are 12 km from this town.

The locality presents certain particular features, because although it is a town close to a tourist center, since its origins it has developed a cultural dynamic of its own identity, much more linked to the lifestyle of a traditional town in Mexico, than to the dynamics that came with the tourist scale of its nearby coasts.

Local and regional government institutions have been pivotal in establishing policies, providing resources, and facilitating citizen participation. Universities, research institutes, and experts in academia and research were able to provide technical expertise, feasibility analyses, and innovative approaches It also included the participation of the private sector, from the neighbors who owned the houses, a restaurant whose construction was symbolic of the locality, to construction companies and material suppliers, whose availability and support made it possible to carry out the chromatic intervention of the facades, providing financial resources, materials and technical knowledge. (Reyes González et al., 2024)

It is important to emphasize the specific characteristics of the chosen street for the project and the historical and symbolic significance of the building that inspired and shaped the project.

On the corner of Hidalgo Street is the restaurant “La Tienda Grande.” The chef and businessman owner, along with his mother, who is originally from the town of Ixtapa, started talking with neighbors about the idea of improving the situation of the street. They sought an intervention that would allow them to rescue the historical value and cultural identity that Ixtapa had many years ago.

"The Tienda Grande" was the first convenience store in Ixtapa in the 1940s. According to neighbors and current restaurant owners, it housed the first telephone in the area, attracting people from the surrounding communities, including the coastal areas of Puerto Vallarta and Bahia de Banderas (Carrillo, 2023) [interview conducted by J. Odetti].

"The store was a gathering place for the community," recalls neighbor Rebeca Fernández.(2023) "Most of the houses on this street and the surrounding ones date back to the 1930s. My dad has lived in Ixtapa since 1933, when the store was inaugurated. When we approached them about this project, all the neighbors said yes. When we thought about the colors, we pictured pinks, bougainvilleas, and Mexican pink - it made our hearts happy." [interview conducted by J. Odetti].

"Nostalgia, identity, and affection for the community. This project brought us backstories and emotions. Hopefully, it will continue with the rest of downtown Ixtapa." (Fernández, 2023)

Figure 2 displays the photographic documents used for the chromatic study and as tools in the in-depth interviews with neighbors and businessmen.

Fig.2. Historical photographs of old Ixtapa

These are examples of some of the conclusions, made possible through the methodology of citizen participation applied to the concept, planning, and execution of this intervention. Urban color becomes an evocative element, reminding feelings, and emotions, and creating meanings that reinforce the cultural identity of a street and open the door to future interventions in the nearby context.

2. Objective

The objective of this article is to present, through a case study, the analysis of urban color as a protagonist element in projects of chromatic and artistic interventions that represent a strategy for the preservation and strengthening of identity and urban cultural construction.

As specific objectives to carry out these proposals, it was proposed to identify the construction of socio-visual - territorial and chromatic perceptions of the urban space to be intervened in, to analyze and characterize from the qualitative study of urban image analysis the chromatic dimensions of the different zones selected for the intervention and to integrate the key actors in the conceptualization and implementation of the proposals of chromatic and artistic intervention in the selected areas.

3. Method

The research design corresponded to a qualitative study with an interpretative and action research perspective, which considered the analysis of the meanings attributed by the research subjects to the case study, seeking to interpret the construction of meanings by applying the various instruments selected.

Through the combination of qualitative and quantitative analysis methods of urban color research, the specific characteristics of color in the locality were explored as a basis for the proposed chromatic and artistic intervention of Hidalgo Street in the historic center of Ixtapa, Jalisco, Mexico.

All this to contribute to the cultural construction of the city, boost tourist activity, stimulate economic vitality, and satisfy the feeling of belonging and identity.

During the period between August and October 2023, fundamental actions were carried out for the execution of the intervention that involved a significant collaboration between educational institutions, neighbors and businessmen. The project's main idea was based on the concerns of local businessmen and neighbors of the street to be intervened; together with them, we worked on the definition of the objectives and scope of the planned intervention on the town's facades.

A total of 80 architecture, design, and visual arts students from the two local public universities were invited to participate in designing and executing the intervention.

In addition, two participatory workshops were conducted with businessmen, neighbors, teachers, and students to collaborate on the concept, socialization, and definition of the project.

The perceptions and cultural constructions of color in the area were also analyzed in order to develop the chromatic and artistic intervention proposal.

In order to document and contextualize each stage of the process, an exhaustive photographic and videographic record was made.

Visual coverage was maintained throughout the development of the project, providing a valuable tool for evaluation and retrospective analysis. Dissemination of progress and achievements transcended the local level, as a media campaign was carried out in the local press, highlighting the relevance of the initiative and its positive impacts on the community. In addition, the project was actively promoted at academic events, consolidating its visibility and recognition in different specialized circles. This set of actions evidenced the effectiveness and comprehensiveness of the planning and execution of the project during this specific period (Reyes Gonzalez, et al., 2024).

The techniques and tools selected were varied. Documentary and field research were conducted, including interviews with long-term neighbors, and analysis of historical documentation and photographs provided by the neighbors.

The action research involved neighbors, business people, and students to determine and analyze the main color characteristics present in the collective imagination of the street residents and the photographic records collected.

From the cartographic analysis, a survey of the area and the street to be intervened was carried out, with analysis and drawing of each façade, observing its state of conservation, identifying its main architectural elements and possible elements to be rescued as elements of heritage and cultural identity.

Two participatory workshops were conducted with neighbors, businessmen, students, and teachers to study qualitative variables. In-depth interviews were also documented and analyzed.

The instruments selected were: field files; drawings of urban images; geographic information systems; interview formats; participatory workshop formats; and questionnaire formats. Generation of chromatic palettes. Generation of chromatic harmonies that were applied in the chromatic and artistic interventions.

All the analysis of the chromatic palettes and harmonies generated was conducted using the Natural Color System. [1]

Table 1 outlines the methodological process of the intervention project and its analysis.

Methodological Process							
Background	**Hypothesis**	**Kind of Research**	**Techniques**	**Instruments**	**Units Analysis**	**Dimensions Analysis**	**Indicators**
Urban color of Architecture, Urbanism, Design. Analyzed in : Photographs period In-depth interviews, Rescue of life stories.	The needs and concerns of neighbors and businessmen link color with their knowledge, expressed in chromatic values, experience, multiplicity, and perception as a result of urban cultural construction.	Qualitative study, with an interpretive perspective (the explicit aspects, conscious, implicit and unconscious subjective reality is under study)	Documentary and field research Action research Cartographic análisis Participatory workshops Photo shooting, Color Scan, Qualitative surveys, Interviews and visual ethnography	Field files; drawings of urban images Geographic information systems Interview formats Participatory workshop formats Questionnaire formats. (NCS) Chromatic palettes. Chromatic harmonies	Facades, furniture and urban landscape. Subjects: inhabitants and businessmen.	Color palettes Chromatic perceptions. (identity, feelings, time, places, landscape and architecture)	Color and facades, ornaments, materials, color palettes with meanings, sentiments and narratives

Tab.1. Methodological process of the intervention project

By including in the methodology of this project the participatory space in the planning, design, and self-management of the intervention, the experiences of its inhabitants, and how they interact and coexist with the colors were involved. The possibility of choosing a palette of colors to intervene in their living space generated the opportunity to make visible their streets, their squares, their buildings, the natural context, their facades, and their textures.

As a last step in the methodology, an evaluation interview instrument was applied to the 16 neighbors who own the intervened facades three months after the intervention was carried out to gather their opinions and evaluations regarding the project and its impact on their perception and coexistence with color in their urban experience.

The proposal for the chromatic intervention in Ixtapa was based on the idea that color is a key visual element that shapes the urban image and contributes to the expression of cultural identity and urban life. The design process included elements aimed at sustainable development, such as social participation and the involvement of community members.

4. Results

The case study focused on creating a chromatic and artistic intervention for a prominent street in downtown Ixtapa. Students and professors interviewed neighbors and business owners of a restaurant located in a significant building in the area. The goal was to understand their concerns, preferences, and needs regarding adding harmony and color to the street. The aim was to enhance the urban image, emphasize the street's identity, and execute murals in the restaurant as part of the project.

The initial challenge of this project was to collaborate with neighbors and business owners to choose the colors for the project. This involved two participatory workshops and in-depth interviews. Specialist teachers provided guidance on chromatic harmonies, color theory, and visual effects of colors in the urban environment.

In a collaborative work, neighbors, teachers, and businessmen chose to start with the selection of colors, based on the analysis of photographs as historical documentation and on the previous work that had been done for the selection of colors for the brand of the restaurant located in one of the emblematic buildings of the area.

It should be noted that for the chromatic design of the brand 'La tienda Grande', we had previously worked with qualitative color study tools, which related them with the life stories of the chef's mother and the chef himself, both Ixtapa's neighbors, as well as with the identification of colors related to the gastronomy of the place and the traditional architecture of the town.

Figure 3 illustrates the process of selecting the color palette to initiate the participatory workshops and the development of the color proposal.

Fig.3. The initial color palette and the two colors with which neighbors, businessmen, students, and teachers began to work the chromatic harmonies for the intervention.

During the two participatory workshops, the pink color NCS S 1070-R20B was selected as the protagonist for realizing the first color harmonies and presenting the proposals for application on the facades.

Subsequently, as can be seen in Figure 3, the proposals of chromatic harmonies based on the color theory of Johannes Itten were worked on, starting with the selected color, pink NCS S 1070-R20B, around palettes of analogous, monochromatic, composite, tone, desaturated and alternate colors.

In a new meeting with businessmen and neighbors, monochromatic harmony was selected as the basis for the entire chromatic intervention proposal and for the execution of the artistic murals on the façade of the emblematic restaurant. Figure 5 shows the selected chromatic palette applied to the chromatic design of the street for the intervention.

As a structural framework for the practice of the final chromatic design, compositional criteria were considered, integrating a dominant color accompanied by subordinate and accent colors. In this context, the following colors were applied:

The dominant color, NCS S 2060 R30B, played a leading role in defining the communicative values of the chromatic combination. It functioned as the central axis and gave visual coherence to the intervention.

As for the subordinate color, the colors NCS S 1070 R20B and NCS S 1060 R30B were chosen. These colors, visually more subdued, fulfilled the function of contrasting or complementing the chromatic combination, providing nuances and depth to the intervention.

Finally, the accent colors, NCS S 6030 R30B and NCS S 2065 R20B, added a distinctive and striking touch to the composition. These colors not only provided visual tension within the color scheme but also contributed direct visual details, enriching the aesthetic experience of the chromatic intervention on the Ixtapa facades.

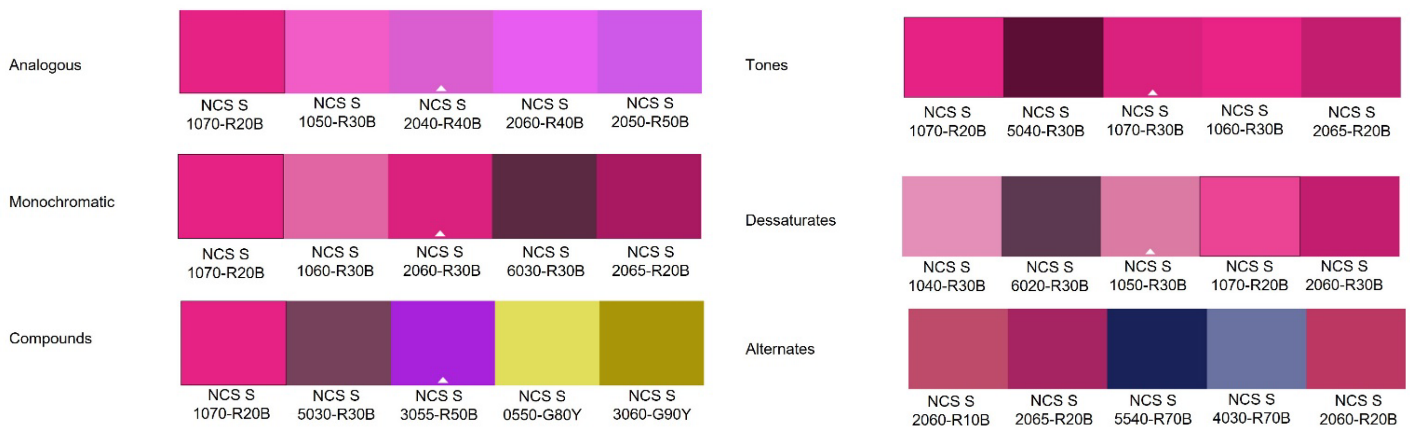


Fig. 4. Chromatic harmonies´ proposal

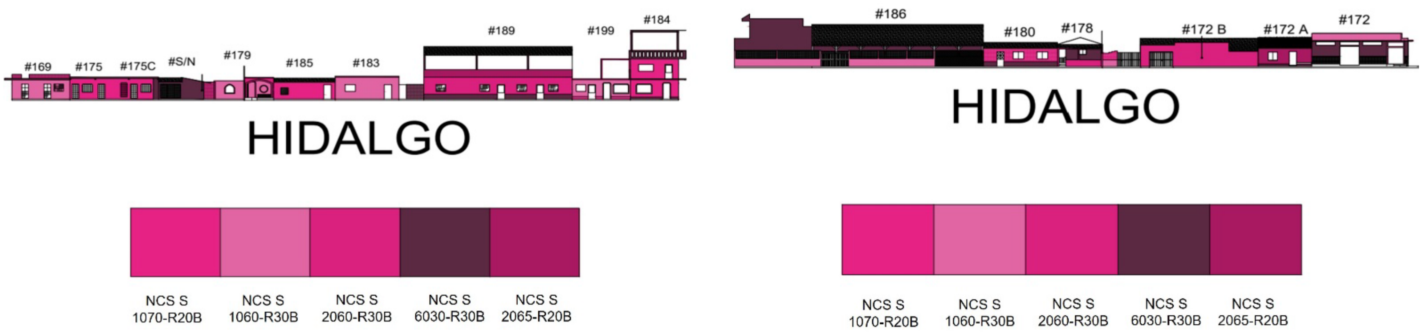


Fig. 5. The monochromatic palette proposal was applied to Hidalgo Street.

With all this defined, all the technical files were generated to organize the work and the execution of the chromatic intervention. Parallel to this, the students of visual arts, together with the students of design and communication, interviewed neighbors and businessmen to rescue the traditions and history of the building in which today's emblematic restaurant and generate with it the proposal of themes for the artistic murals that would intervene the facade of the restaurant.

The exercise of designing the murals and their final application and execution was a new learning experience, in this case, for the visual art students, who had to adjust their designs and execution to a restricted chromatic palette, which also allowed them to think about color and its integration from the scale of the sketch to the large format of the mural, but also to the integration with the rest of the urban chromatic design.

Figure 6 shows the final result of the execution of the intervention. Here we can see how all the key actors participated in all the stages of the project, since they also had the experience of painting, coordinating as a team, and generating from the community work a solidary contribution to the community, recognizing at the very moment of the application of the paint the power of transformation of the perception and aesthetics of the urban image through design and color.

It is worth noting that after the chromatic execution, as shown in Figure 6, the multimedia design students developed a video in which they captured the stories that neighbors, students, teachers and businessmen were able to share about this experience, narrating anecdotes from before, during and after, as well as reflecting on the entire project carried out.

Fig. 6. Images of the process of chromatic and artistic intervention on Hidalgo Street, with the participation of neighbors, teachers and students.

As a final step, an evaluation instrument in the form of a semi-structured interview was applied to each of the participants, 80 in total between students and teachers and the 16 owners of the intervened facades to reflect on the opportunities, successes, challenges, and strengths of the project, as well as to record the impact that, a few months after its implementation, the chromatic intervention has generated in the community.

The results of these interviews highlighted the following:

Figure 8 shows the comments regarding the general perception of the project and the degree of satisfaction of those involved with the project. Where it is possible to observe, for the most part, the positive perception of the results of the intervention, the fulfillment of its purpose, and the desire to be able to continue supporting or participating in similar projects for the neighborhood. It should also be noted that in the selection of the themes for the artistic murals, the great majority felt very satisfied, as well as in the improvement of the urban image produced by the chromatic intervention. Regarding the choice of the chromatic palette, opinions were divided; some of the interviewees expressed other chromatic preferences, but they understood that the choice was due to the history of color in that street and its relationship with the identity of the locality.

Fig. 7. mages of the in-depth interviews were realized and edited into a promotional video for the project.

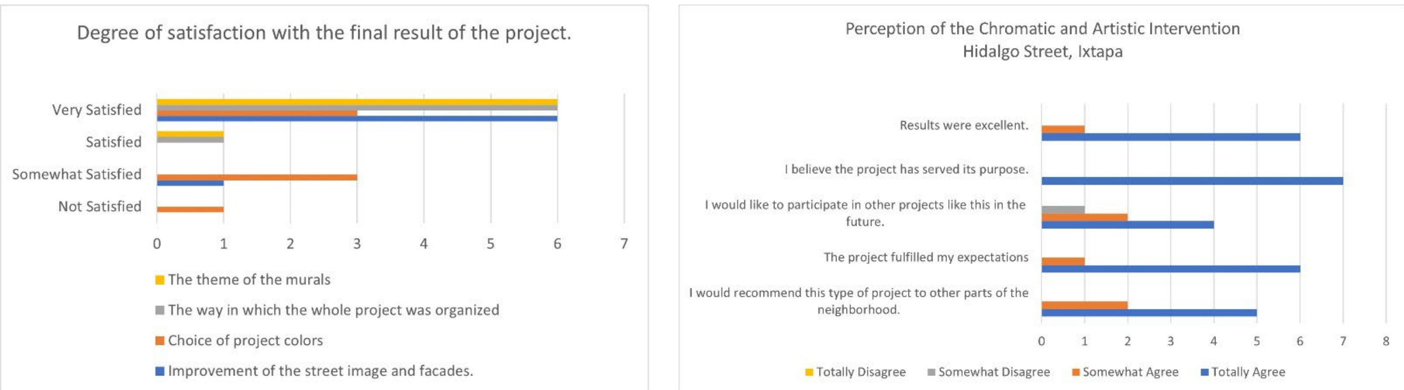


Fig. 8. General perception and degree of satisfaction with the final result of the chromatic and artistic intervention project.

Next, the interview form included some open-ended questions regarding the aspects they liked most about the project and the feelings, sensations, emotions, or stories that the project had provoked in the interviewees. The most outstanding contributions with their keywords are included in Figure 9.

Fig. 9. Keyword cloud of qualitative appraisals of the project and the perception of the project by the interviewees.

In the graph presented, we can observe appreciation and associations of the chromatic intervention with certain predominant emotions, such as joy (directly related to the power of color as a communication element and mood stimulator). Words such as identity, revaluation, and attention, which are related in the messages of the interviewees with the power of color and chromatic intervention to revalue the urban image of the street and rescue the symbolic aspects of culture, such as those related to identity and sense of belonging, also stand out.

5. Discussion

In the current context, many cities and regions attach great importance to forming an urban image based on the study of color to develop a sustainable urban life. It is widely recognized that the research and urban proposals of color contribute to stimulating the city's vitality, preserving the history of its localities, and contributing to the sustainable development of urban culture.

From the economy, urban chromatic design can promote tourism (Smedal, 2019); from the social aspect; the use of color can promote social interaction strategies, revitalize urban areas and improve the sense of belonging with the built environment and the urban landscape (Boeri, 2017), (O'Connor, 2023).

It is interesting in this sense to rescue the element of citizen participation in this project, to achieve an impact in more than one of these aspects.

Even though the project was only able to become a reality in one street of the locality, the exercise can set a model to manage other interventions in other streets of Ixtapa and other areas of urban border context in a tourist city such as Puerto Vallarta.

From the visual-perceptual approach of Jean Philippe Lenclos (2004), who introduces the concept of 'geography of color', this project manages to point out how the specificity of the traditional colors built (in this case from the chromatic study of an emblematic construction, as was 'La Tienda Grande', is closely related to the environment, regional differences and, above all, with the use of local building materials.

Therefore, from the intervention and urban chromatic studies, the signs of identity of a place can be reinforced, cultural landscapes can be built, and cultural diversity can be respected from the design, incorporating elements and colors based on their cultural studies. (Lenclos, 2004) (Spillmann, 2019) (O'Connor, 2023)

Thus, in this work, we propose to put special emphasis on the study and proposal of chromatic and artistic intervention in the selected case, as a visual element of the urban image and as a component of identity formation and symbolic expression of urban life.

From sociology and urban anthropology, the concepts of perception and color in the city are studied through the conceptions of cognitive-valuative systems that develop in urban contexts and that are the product of cultural dynamics, such as the processes of urban cultural construction (Signorelli, 1999).

In a similar sense, Wirth Louis (2011) explains how the city can be'read' from different configurations that involve urbanism as a way of life and highlights for this purpose the particular characteristics of a city from its physical structure, its system of social organization, and the set of attitudes and ideas that participate in the collective behavior and the symbolic construction of the city.

In the case study presented, this is evident from the previous concerns expressed by neighbors and businessmen to the evaluation of the impact of the very particular chromatic palette selected, and the emotions and sensations that this has provoked, both in the inhabitants and in those who begin to visit the street that is currently known as 'pink street of Ixtapa'.

Along the same lines, Veronica Zybaczynski (2016) highlights the importance of works that include the rescue of color as an element of identity, underscoring how each color response in the city is a design and that this response is due not only to the justification derived from history and from a pre-existing, but from a goal of the power of color to resolve the contradictions dictated by the transformations of the city, which involve both the historic urban fabric and the suburbs.

An example of this has been the opinions and concerns of the locals and entrepreneurs, who in the participatory work, for example, expressed their desire to "include colors, reminiscent of Mexico, something warm, colors that remind us of Mexican cuisine and particularly of the traditional recipes of the families of Ixtapa, mainly of the neighbors, women who pass the recipes from generation to generation and who come to inspire the chef of the restaurant" (Carrillo, 2023).

This is how neighbor Rosa Isela Medina (2023) described it: "The colors of Ixtapa are characterized by their vibrant colors and pink is very present, for example in the bougainvilleas (flowers that abound in the decoration of the houses in the area) and with which teas and drinks are also prepared. [Interview by J. Odetti].

Also in the workshops, from the training offered by the teachers and the observation of the participants, it was possible to highlight how pink appears as a significant Mexican color element, which can be found in numerous examples in Mexican architecture and the history of art, with paradigmatic artists and architects such as Luis Barragán, Ricardo Legorreta and his disciples, as well as in Jalisco in the work of plastic artists such as Chucho Reyes. As Anna Marotta (2011, p 119.) comments "The influence of Chucho Reyes was decisive for Legorreta in his use of color and fusion with popular arts, although his use of color could seem intuitive and free".

All of them are symbols of the power of color in a country where it is abundant in every corner, from natural and gastronomic manifestations to celebrations and expressions of culture.

One of the conclusions of these desires, inspired by the work of the workshops, was overwhelming: "May Ixtapa be painted pink".

From the methodology used, there are two aspects to highlight as successes, one is the inclusion of citizen participation throughout the exercise, which can be linked to the elements that constitute the objectives of sustainable development, to integrate them into the design process, specifically social participation in the development and integration of key actors in the community.

And secondly, the concept of chromatic and artistic intervention of facades, a concept that with the passing of time has begun to gain popularity, not only in Ixtapa but also in other zones of the periphery of the city of Puerto Vallarta. From municipal authorities to neighbors of different zones are beginning to pay attention to this methodology as a possible method to detonate developing zones and rescue forgotten or abandoned urban areas for not belonging to the traditional tourist circuits.

In this case, most of the initiative was led by young entrepreneurs and some neighborhood leaders of the street, but the municipal authorities, for example, were not present. Ideally, it would be hoped that in new interventions this alliance between neighbors, entrepreneurs, students, and academics would be enriched and accompanied by the municipal or state government sector, depending on the degree of impact sought.

Finally, it is also necessary to observe the scale of the project, since it has been an intervention carried out in a peripheral zone of a tourist city that is characterized for being a sun and beach destination, but that is part of a country, like Mexico, where the projects of rescue and design of the urban color have different dimensions.

From the rescue of historic centers that can be declared World Heritage Sites (such as the case of the City of Zacatecas, or Guanajuato, in the center of the country, or Campeche in the Mexican Southeast, etc.). Even initiatives led by non-governmental organizations that use color and urban art to dignify or strengthen the social fabric of popular areas that are suburbs of large cities, such as the example carried out in Santa Catarina in Nuevo Leon, by the Association Civil Corazón Urbano AC.

All of them are examples of how color is lived, felt, signified, and experienced in diverse city contexts, but in which it becomes an element of urban cultural construction.

7. Conclusions

In this article and with the case study presented, we intend to highlight the reflection on the role of color as a protagonist element of life in the city, evocative of emotions and perceptions, which, when taken to the scales of intervention in the urban image, can account for the processes of the cultural construction of the same by all the actors involved in the experience.

It is also important to highlight the study of urban color from a perspective that opens our gaze and positions us as subjects who experiment with colors. In this sense, color becomes an evocative element of countless meanings, with which we can narrate, express, communicate and give meaning through the various disciplines that consider it as a protagonist element and ultimately as an element of cultural identity in the city.

On the other hand, the advances in chromatic works that begin to include the subject of the perception of its inhabitants in Latin America represent an opportunity to reflect on the complex realities of the Latin city in general and on the multiple chromatic scenarios that account for a cultural richness and an experience that is not only objective and linear but is built with the passing of time and becomes more complex with the participation of those who transit and live the city. (Odetti, 2019).

An essential aspect to contribute this case to the studies of urban color has been the concept of chromatic and artistic intervention, where color and art are conceived as transforming elements of life in the city. This, together with the participatory design methodology, highlights the voices of those who participated in the intervention, the meanings that this project denotes in the inhabitants, in the students who participated and collaborated, in the initiative of the businessmen, and in the experience of linking the university with the community.

Thus, in the project presented here, the most relevant aspect is how color and mural painting became protagonists and starting points to improve the quality of life and highlight the values of cultural identity in the community. In addition, the students of both universities involved in the project benefited from their learning processes and contributed directly to the development of the locality.

Another interesting aspect to rescue for future interventions and methodological reflections on the study of urban color has been the multidisciplinarity, which the project included.

The richness of studying and intervening chromatically with a street of a locality, with diverse looks and different languages, such as the chromatic design itself, the themes and styles of the murals, and the previous and later process of documentation with the videos, the rescue of the oral history that could be registered in them and the multiple ways of documentation used, to be able to think about color from a multiple, diverse and uninterrupted perspective.

8. Conflict of interest declaration

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

9. Funding source declaration

The authors received no financial support for the research, authorship, and/or publication of this article. However, the results presented here have been part of the research project registered at the Jose Mario Molina Pasquel y Henriquez Technological Institute with registration number: ID P1618B-SUBIP.

10. Acknowledgment

I would like to express my most sincere gratitude to the authorities, students, and colleagues of the José Mario Molina Pasquel y Henriquez Technological Institute, Puerto Vallarta Campus, for supporting our research work, their useful comments, and their collaboration. I would like to thank the entrepreneurs of the restaurant, La Tienda Grande, for trusting us with the execution of the project presented here. And to the authorities and teachers of the University of Guadalajara at the CUCOSTA campus, especially to the coordinator of the visual arts career, Maria Cristina Mercado, for all her support and collaboration throughout the process of project management and for her valuable contributions to this research.

11. Short biography of the authors

Jimena Vanina Odetti - is a doctorate in Design, a master's degree in cultural promotion and development, and a degree in Visual Arts. She is a research professor at the National Technological Institute of Mexico, specifically at the Puerto Vallarta Academic Unit of the José Mario Molina Pasquel y Henriquez Technological Institute. She is the leader of the Academic Research Group of Design and Innovation. Her research focuses on the study of color in architecture, urban planning, art, design, and culture. She is a member of the editorial board of many journals and belongs to the National System of Researchers of Mexico. She also is a member of the AIC Study Group on Environmental Color Design.

Alberto Reyes Gonzalez - He is an architect with undergraduate programs: Urban Design and Environmental Design Laboratory, Architectural Design Laboratory, at the Polytechnic of Milano, Italy. Master in Sustainable Development and Tourism from the University of Guadalajara. Doctorate in Sciences for the Development of Sustainability and Tourism from the University of Guadalajara. He is a member of the Academic Research Group of Design and Innovation. He is a member of the National System of Researchers, CONACHYT. He is a Research Professor at the National

Technological Institute of Mexico, specifically at the Puerto Vallarta Academic Unit of the José Mario Molina Pasquel y Henriquez Technological Institute. His research involves sustainable architectural and urban design processes and studies of citizen participation.

Andres Enrique Reyes González - He is an academic with research and leadership experience in education. He has a strong academic background, including undergraduate degrees in International Business and Law, as well as a Master's in Business Administration. In addition, he has a PhD in Science for Development, Sustainability and Tourism. He is part of national and international research networks, which evidences his commitment to the advancement of knowledge in his discipline. In addition, he holds the position of president of the Graduate Council in Administration at the National Technological Institute of Mexico, specifically at the Puerto Vallarta Academic Unit of the José Mario Molina Pasquel y Henriquez Technological Institute. He is a member of the Academic Research Group of Design and Innovation.

He is a member of the National System of Researchers, CONACHYT.He is a Research Professor at the National Technological Institute of Mexico, specifically at the Puerto Vallarta Academic Unit of the José Mario Molina Pasquel y Henríquez Technological Institute. His leadership in this position underscores his ability to direct academic programs and promote research in his field.

Fernando Daniel Valdez Olmos - He holds a degree in Architecture from the Instituto Technologic Superior de Puerto Vallarta, specializing in Urban Planning. He holds a Master's Degree in Business Administration from the University of Guadalajara, as part of the programs of excellence recognized by CONACYT. He is a Research Professor at the National Technological Institute of Mexico, specifically at the Puerto Vallarta Academic Unit of the José Mario Molina Pasquel y Henríquez Technological Institute. He is a collaborator of Academic Research Group of Design and Innovation. He has a PhD in Cultural Management from the University of Guadalajara.

Notes

[1] The Natural Color System (NCS) is a psychometric model for color description and also a practical application of Hering's opponent-color theory. (Hård & Sivik, 1981)

Licensing terms

References

Boeri, C., 2017. "Color loci placemaking: The urban color between needs of continuity and renewal". Color Research & Application 42 (5), pp. 641-649.

Dabbagh, E., 2019. "The Effects of Color and Light on the Beautification of Urban Space and the Subjective Perception of Citizens.". Int. J. Eng. Sci. Invent. (IJESI), pp. 8:20-25.

IIEG, 2020. Análisis sociodemográfico de la localidad Ixtapa en Puerto Vallarta, 2020, Guadalajara: Instituto de Información Estadística y Geográfica de Jalisco.

Lenclos, J.-P. D. L. F. B. a. G. P. B., 2004. "Colors of the world: the geography of color:. s.l.:WW Norton & Company..

O'Connor, Z., 2023. "Environmental color interventions on a macro scale: Tactical urbanism and issues of global concern.". Color Research and Application 48 (5), pp. 578-584..

Odetti, J. V., 2019. Los colores de Puerto Vallarta, en la construcción cultural urbana de una ciudad turística. 1990-2016.. Buenos Aires: Universidad de Palermo.

Reyes González, A., Reyes González, A. E., Odetti, J. V. & Valdez Olmos, F. D., 2024. Participación Ciudadana a partir de la intervención cromática de zonas periurbanas. Cuaderno 219 | Centro de Estudios en Diseño y Comunicación., pp. 303-320.

Signorelli, A., 1999. Antropología Urbana. México: : Anthropos Editorial..

Smedal, G., 2019. "The Longyearbyen Project: approach and method.". Colour for Architecture Today, pp. 73-77. .

Spillmann, W., 2019. "Unity in diversity at Kirchsteigfeld, Potsdam.". Colour for architecture today,, pp. 36-38..

Wirth, L., 2011. Leer la ciudad. Ensayos de antropología urbana. El urbanismo como forma de vida. ,. Revista de estudios sociales., pp. 110-115..

Zybaczynski, V., 2016. [Colour Studies] Re:Placing Colours. Evaluation of the Chromatic Interventions on the Blocks of Flats in Bucharest, Romania.. Santiago de Chile: Asociación Chilena del Color, s.n., pp. (págs. 39-43)

Chromatic reintegration: Color Matching Challenges in Polychrome Wooden Ceilings

Karla Muñoz-Alcocer[1,3], M. Luisa Vázquez de Agredos-Pascual[2], Stephanie Alejandra Estrada Portillo[3]

[1] Instituto Nacional de Antropología e Historia, Centro INAH Chihuahua, Mexico

[2] Dpto. Historia del Arte, Universidad de Valencia, Spain

[3] Laboratorio de Patrimonio Histórico - Misiones Coloniales de Chihuahua A.C

Corresponding author: Karla Muñoz-Alcocer (karlamunozalcocer@gmail.com)

ABSTRACT

This paper presents a comprehensive study on the materials, manufacturing techniques, and conservation strategies used in the polychrome wooden ceilings and walls of the Church of Santa María de Cuevas in Chihuahua, Mexico, whose origin dates back to Spanish colonial times. It focuses on the chromatic reintegration process and the significant findings discovered during the restoration project. The renowned Italian technique of sottotono (lower color tone) was employed to establish color reintegration criteria, allowing for a clear distinction between restored and original paint in the ceilings situated 12 meters above the floor. The varying intensities of the original paint posed challenges, particularly in beam ceilings where achieving smooth variations was not feasible. Floral decorative motifs exhibited a consistent red-orange hue, while yellow displayed variations, especially in areas affected by water damage. The blue color, prominent throughout, exhibited notable variations in hue, with two different saturations observed. The restoration process revealed unique insights into the design techniques used and variations in motifs and spacing. These findings deepen understanding of materials, techniques, and conservation strategies employed in Spanish colonial churches in the region, providing valuable knowledge for future preservation efforts.

KEYWORDS Color restoration, chromatic restoration, blue indigo, Santa Maria de Cuevas, Chihuahua, Mexico, Jesuits, Spanish colonial missions.

RECEIVED 01/08/2024; **REVISED** 18/10/2024; **ACCEPTED** 02/11/2024

1. Introduction

For the past 25 years, collaborative efforts involving government and private sectors have focused on researching, conserving, and promoting Chihuahua, Mexico's cultural heritage, particularly buildings from the Spanish Colonial period and the 19th century. A key project is the conservation of the 17th-century mission church of La Asunción de Santa María de Las Cuevas, supported by national and international entities. In 2021, Misiones Coloniales de Chihuahua A.C. led the conservation of the church's polychrome wooden ceiling with support from the Eka Nawerame fiscal stimulus program and local community involvement. This project establishes standards for future preservation work, aiming to preserve the entire decorative scheme of the church.

1.1. *Geographic and natural context*

Chihuahua, the largest state in Mexico, spans an area equivalent to half of Spain, resulting in diverse climates and vegetation. Santa Maria de Cuevas, located in the state's central region, has a semi-dry climate with desert vegetation and underground water that feeds a stream flowing to the San Pedro River year-round. Summer temperatures can reach 35°C, while winter temperatures can drop below 3°C (CNA, 2024).

The region features large rock formations, canyons, and caves with pre-Hispanic rock paintings. Natural resources include lime, gypsum, limestone, quartz, barite, and magnesium. Vegetation mainly consists of cacti, mesquite (*Prosopis glandulosa*), and tascate (*Juniperus deppeana* and *Juniperus durangensis*), with nearby pine-oak forests also present (Economía, 2011).

1.2. *Historical context*

Historical records indicate that a mission visit was established in Cuevas by 1663, though there is no mention of a church at that time. The first record of a church appears in 1678 (Roca, 1979), when its construction is reported. Recent research, however, suggests that the current building was constructed between 1696 and 1700 by Jesuit missionary Luis Mancuso, who incorporated existing walls and initiated an architectural and artistic project. Mancuso commissioned painter Domingo Guerra to create a wooden ceiling and murals in the nave and presbytery, depicting the Assumption of the Virgin Mary. Guerra's signature, dated 1700, appears on the upper frieze of the presbytery. In 1753, the region's mission administration was transferred to the Archdiocese of Durango, and in 1758, Bishop Tamarón y Romeral moved the parish seat to San Lorenzo, leaving Santa María without a resident priest (Márquez, 2004). These historical insights clarify the timeline and significance of the church and its decorative artwork.

Fig. 1. Aerial view of the Spanish Colonial mission church of La Asunción de Santa María de Cuevas. (Photo: Misiones Coloniales de Chihuahua A.C., 2021).

1.3. *Social context*

The region where Santa Maria is located has a predominantly mestizo population, which refers to individuals of mixed European and Indigenous descent. However, there are also a few Rarámuri families living in the community. The economic activities in the area revolve around agriculture and cattle raising, with the availability of water playing a significant role in sustaining these activities. It is important to note that many families in Santa Maria have at least one member, or sometimes the entire family, living in the United States. These family members provide an important source of economic resources through remittances, which contribute to the community's livelihood and well-being.

The church holds a central role within the community's social and cultural fabric, promoting different activities that contribute to community strengthening. The annual Fiestas Patronales, celebrated on August 15th, in honor of the Assumption of the Virgin Mary, are particularly significant. During these festivities, a series of gatherings and dances are organized, including a Mass celebration and the traditional jaripeo or rodeo.

To ensure the maintenance and proper functioning of the church, a dedicated church committee is responsible for overseeing its upkeep and organizing activities for its benefit. These activities include various celebrations such as baptisms, first communions, and funerals. The members of the committee are chosen and assigned by the community, with new members being approved and appointed every three years. This community-led approach highlights the involvement and collective responsibility in preserving and cherishing the church as an integral part of their cultural heritage.

2. The polychrome wooden ceiling

The polychrome wooden ceiling of the Church of Santa María de Cuevas is a remarkable feature that sets it apart from other churches in the country. It is considered the oldest example of a mostly intact polychrome wooden ceiling in Mexico. The decorative surfaces in the nave and presbytery of the church are adorned with intricate figures and elements, each carrying its own iconographic meaning (Munoz-Alcocer *et al.*, 2016; Muñoz Alcocer *et al.*, 2017).

In the case of the baptistery, which is located to the far right of the east facade near the main entrance, it serves as a chapel that houses a recent sculpture of the Sacred Heart of Jesus. The fixed baptismal font is likely movable, indicating its flexibility for different ceremonies and needs.

The ceiling of the baptistery is composed of ten north-south beams of varying sizes, which are adorned with geometric vegetal motifs painted in yellow and blue, along with black lines. The sides of the beams feature flower and leaf patterns, adding an additional layer of decorative detail. The wooden panels between the beams are decorated with red four-petaled flowers and blue leaves. The spaces between these elements display red and green flowers framed by blue circles. This intricate and colorful design creates a visually striking and ornate ceiling. Similar to the rest of the church, the baptistery's ceiling is completed with a marbled-paint wooden cornice, providing a finishing touch that enhances the overall aesthetic appeal and cohesion of the interior.

The attention to detail, the use of vibrant colors, and the incorporation of organic and geometric motifs showcase the skilled craftsmanship and artistic expression that went into creating the polychrome wooden ceiling of the baptistery in Santa María de Cuevas Church.

2.1. *Materials & Techniques*

The materials and manufacture technique of the decorative surphaces of Santa Maria de Cuevas church have been studied in deep and in major context with other Spanish colonial churches in Chihuahua (Muñoz Alcocer, 2018). Multi-technical analysis of non-invasive and invasive techniques (Muñoz-Alcocer *et al.*, 2020) have determined the pigments and dyes used on the decoration of Santa Maria’s polychrome wooden ceilings and walls. In addition, for the purpose of the conservation project, new samples were taken and analyzed by the Laboratorio de Patrimonio Histórico to confirm the previews results (Table 1).

2.1.1. *Colorimetric study*

The portable Spectro 1 by Variable was used as spectrophotometer. It features an 8mm diameter measurement size, within a spectral interval of 10 nm, covering a range of 400 to 700 nm, using full-spectrum LEDs. The device measures in just 1.5 seconds and has a short-term repeatability of 0.05 ∆E00. Its inter-instrument agreement, tested on 32 ceramic tiles, is an average of 0.2 ∆E00, with a maximum of 0.5 ∆E00. The optical geometry is diffused, and it supports illumination types A, F2, D50, and D65, with 2-degree and 10-degree observers.

A avarage of 4 mesurments were taken by beam and panel base on the blue color hue of ceiling section. In addition comaparison masures were taken between the orginal polychrome and the restoration areas, before and after the color correction.

ANALYTHICAL STUDY	WOOD	GROUND	COLORS				
FORS XRF Optical Microscopy ATR-FTIR Spectrosco	Pine wood	Gypsum (CaSO4.2H2O) Hemihydrate CaSO4.1/2 H2O)	Yellow ochre Iron Oxide	Red ochre Iron Oxide	Indigo	Malaquite CuCO3· Cu3(OH)2	Iron Oxide?/carbon black

Tab. 1. Technical analysis & materials results

2.2. *State of conservation*

The north section of the baptistery partially collapsed due to heavy rains in the 1980s, requiring the replacement of some wooden planks. While most beams were in good condition, the wood of the cornice in both corners of the north wall deteriorated significantly. Large losses of the ground layer and polychrome were visible near the damaged areas, whereas the south wall appeared intact.

Diagnostics revealed the ground layer was made of calcium sulfate (dihydrate, hemihydrate). Originally, gypsum stucco filled the unions between panels and beams to create a continuous decorative subphase, but this stucco was lost on the north side of the ceiling up to its center. In areas not damaged by water, some panels still retained stucco on the borders, though with poor cohesion and adhesion (Figure 2).

Paint loss corresponded to ground layer deterioration. Colors remained stable in unaffected areas, maintaining consistent tone and intensity except for blue. This is explained by the organic nature of the component that provides this blue coloring, as we will see later: indigo, from different species of Indogofera that were cultivated in America in colonial times, with special emphasis on *Indigofera suffruticosa Mill*.

To prepare this blue, known as Mayan blue, the indigo dye was precipitated in inert substrates of capillary clay called palygorskite (magnesium aluminosilicate), and after this, the aforementioned combination was baked at temperatures between 250ºC and 300ºC, giving rise to a pigment -hybrid lacquer, much more stable than the initial indigoid dye. (Doménech and Doménech-Carbó, 2006; Doménech *et al.*, 2007, 2009; Vázquez de Agredos Pascual, Doménech Carbó and Doménech Carbó, 2011)

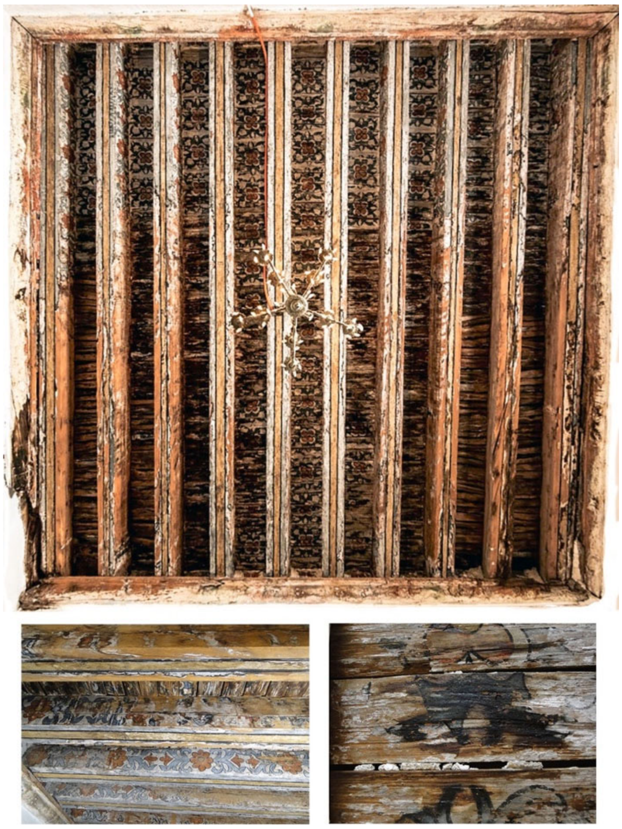


Fig. 2. General view and details of the polychrome wooden ceiling of the baptistery before interventions. (Photo: Montes-Trevizo F., Muñoz-Alcocer,K.,2024).

Alternatively, other substrates inert to palygorskite were used: from other clay silicates of capillary nature to calcareous matrices, among others. In the case of Santa Maria studies indicate the use of gypsum as mortar to produced the blue pigment. The central beam lost most paint intensity, while blue on the borders and panels retained its vibrancy. This discoloration, initially thought to be due to window light, was also found on the interior-facing side of the same beam, suggesting other factors may contribute to the fading (Figure 3).

Fig. 3. View of the beams facing window light. It is possible to observed the color blue hue diffrences between the beams (Photo: Muñoz-Alcocer,K.,2024).

3. The Conservation project

The comprehensive restoration of the church of Santa María de Cuevas and the close relationship between specialists and community members will not only safeguard the building but also create an inclusive environment for social participation. This will contribute to job creation, a sense of belonging, and the strengthening of social fabric, thereby empowering the community to explore collective processes for the common good, enhancing their cultural assets and considering them as a factor for social and economic development. This community and inclusive approach also allows us to generate, through the conservation and dissemination of Cultural Heritage, spaces 'of human occupation with meaning and meaning', favorable for individual and community well-being, following paradigms linked to areas of Health Sciences and Integration Social, as is the case of Occupational Therapy (AOTA, 2008).

3.1. *Conservation treatment & Criteria*

The proposed intervention process for the restoration is based on international guidelines and the criteria established by INAH (National Institute of Anthropology and History). The approach follows principles of minimal intervention, respect for originality, and the use of materials similar to the originals.

The restoration of the polychrome narthex ceiling, which serves as a model for the overall project, aimed to achieve a comprehensive understanding of its narrative and decorative interpretation in relation to the church's decorative painting. Each segment of the ceiling is seen as part of a cohesive whole. The methodology for the restoration consists of five stages: 1. Preliminaries; 2. Stabilization of the structure; 3. Stabilization and consolidation of the polychrome; 4. Chemical and mechanical cleaning; 5. Chromatic reintegration of the polychrome (Table 2).

STAGE	MATERIALS	PROCESS
Preliminaries		• Photographic & Digitalization • Deterioration mapping • Dirt cleaning
Consolidation	• Fish glue	• Injection around the paint flake
Cleaning	• Deionized water • Neutral soap	• Mostened swabs • Mechanical cleaning with scalpel
Ground reintegration	• Calcium suphate • Animal glue	• Brush application covering the ground layer lossess and new panels
Color reintegration	• Watercolors according to original pigments and dyes	• Brush application covering the paint lossess under the *Sottotono* chromatic criteria (lower tone under the original)

Tab. 2. Conservation treatment process

It's important to note that this paper specifically presents the results of the conservation process conducted to recover the polychrome of the ceiling, with a particular focus on the chromatic reintegration of the blue. It does not address interventions related to the roof structure of the church.

3.2. *Digitalization*

The ceiling was photographed by photogrammetry technique in order to optain a 3D model of the polychrome ceiling before and after the conservation treatment.

A Nikon D850 camera, with a 14-24mm f/2.8 lens, used at a focal length of 18mm, f/2.8, ISO 100, and variable shutter speeds ranging from 1 second to 1/60 second.

A total of 252 images were taken to cover 6.94m^2 area obtaining 268,568 points.

The digital images provided a perspective view of the ceiling and, through software, a flat view of the ceiling, a mapping of the structure and state of preservation of the pictorial layers and, for the purposes of this paper, the color degradation (Figure 5).

*Fig. 4. Conservation treatment application, training & community outreach (Photo: Muñoz-Alcocer, K. & Jaquez Sotelo J., 2024***.**

Fig. 5. Photogrametry image of the ceiling before the intervention. It Is possible to observe the three face-sides of the beams. Note the blue color tone variations between the beams, including at beam-face that is not exposed to light. (Photogrametry & imaging: Misiones Coloniales de Chihuahua A.C., Montes Treviso F.,2024).

3.3. *Training program & Community outreach*

The community's involvement in the conservation project is crucial for raising awareness about the importance of the ceiling artwork and the challenges of preserving polychrome ceilings. The project includes a technical training program for six local women and one woman with art studies, equipping them with the necessary skills to contribute to the preservation efforts. Workshops and presentations are also organized to educate the community and visitors about the unique decorative surfaces of the church. These activities aim to emphasize the historical and artistic value of the artwork and encourage community members to take pride in and advocate for the conservation of their cultural heritage. The interactive workshops and presentations facilitate learning about the techniques and materials used in creating the artwork and foster discussions about its significance and conservation challenges. Overall, the project seeks to deepen the community's appreciation and understanding of the church's decorative surfaces.

4. Results

The conservation project of the polychrome ceiling of the baptistery yielded significant results, not only in terms of recovering the structure and aesthetic appearance of the ceiling but also at the socio-cultural dimension level, as explained below. Although the complete process of the intervention will be mentioned, the chromatic reintegration of the blue indigo will be discussed in more detail due to its relevance and the nature of this paper.

4.1. *Treatment*

4.1.1. *Wood structure*

The intervention on the wood structure permitted the recovery of the stability and appearance of the wood panels that were lost during the collapse of both angles. The panels were made of cedar wood, matching the variety and dimensions of the originals to create a similar appearance between the new beams and the originals. Additionally, new wood inserts were added at both corners of the wood cornice to maintain a continuous visual appearance around the ceiling. Cedar wood was chosen because it is more stable than pine, and it also allows for a clear distinction between the original wood and the wood used in the restoration.

4.1.2. *Cleaning*

The dark water stains that covered a large part of the panels on the north side of the ceiling were cleaned with deionized water. During the cleaning process, it was possible to identify a layer of walnut-colored, water-based stain applied directly to the wood and over the original paint. This created significant difficulty in cleaning the polychrome, necessitating the use of neutral soap in some areas to achieve a higher level of cleanliness. Although it was decided not to insist on cleaning in areas where the color came off during the process, it was possible to recover the overall readability of the decorative motifs.

4.1.3. *Ground layer reintegration*

The stucco applied to cover the ground layer losses was made of calcium sulfate dihydrate with animal glue. This process permitted the identification and highlighting of original paint particles and sections that were previously not visible to the naked eye. In the south area of the ceiling, where the polychrome is well-preserved, the ground layer presents a gray tone instead of white, as found in the narthex ceiling or visible in other parts of the church. To prevent a strong contrast between the original background and the conserved sections, a layer of colored-gray stucco was applied once the chromatic reintegration was concluded, except for the black underline.

4.1.4. *Chrormatic reintegration*

The criteria for the color reintegration of the decorative motifs on the ceiling followed the well-known Italian technique *sottotono*. This method of chromatic reintegration involves applying a lower tone in the newly restored areas compared to the original paint. The same approach was used in the restoration of the polychrome wooden ceiling of the narthex, as previously described. This technique was chosen because it allows for clear and appropriate differentiation in the color reintegration of the ceilings in the nave and presbytery, which are located 12 meters above the floor.

The variation in hue intensity of the original paint posed a challenge for the *sottotono* method, especially on beam ceilings where creating a softer variation is not as feasible as on flat surfaces. The red-orange color of the floral decorative motifs generally maintained a consistent hue intensity. However, the yellow exhibited more variations, particularly in the north section where water damage had significantly deteriorated the color, turning it almost brown in some areas instead of the original yellow ochre. The blue, being the predominant color used on the ceiling, showed significant variations, as mentioned earlier in Figure 3. It was evident that two different blue saturations were applied, as seen in the inscription (lines without meaning) made by the artist with a darker blue than the lighter blue used on the lower side of the beam (Figure 6). The panels were painted in a darker blue hue, while the sides of the beams, especially the bottom, were painted with a lighter or less saturated blue. This differentiation was likely intended to create depth and visual contrast in the ceiling's appearance.

Fig. 6. View of the bottom side of the beam with the inscription or lines in dark blue over the light blue of the beam (Photo: Muñoz-Alcocer, K.,2023).

The chromatic reintegration was executed using watercolors, prepared based on the original materials identified through technical analysis. Iron oxide pigments were used to produce the red and yellow colors, malachite for the green, indigo for the blue, and carbon black for the borders of the decorative motifs.

The lower tone (*sottotono*) was determined to establish differentiation between the original paint and the restored areas. This was relatively straightforward for the red, green, and yellow colors. However, determining the lower tone for the blue areas was more complex. The center beams, which were largely exposed to light from the windows, exhibited an almost transparent blue hue against a white-gray background. In these areas, no pigment runoff from water damage was detected, unlike the bottom sides of the beams, where the colorant material concentrated due to water infiltration. It is important to note that the degradation of the blue color on the central beams was not solely due to light exposure. Beams on the interior side (without direct light exposure) also showed tone degradation, similar to beams facing the window. This is likely due to the organic nature of the indigoid blue pigment used, which resembles Mayan blue, as discussed in previous publications (Muñoz Alcocer, 2018; Muñoz-Alcocer *et al.*, 2020), This suggests a continuity of its production after the Pre-Columbian period.

The chromatic reintegration followed the original paint hue of each specific beam or ceiling area, as it was not feasible to use a single hue for all areas based on the darker sections of the ceiling. Doing so could have created misleading visual results when viewed from the floor and might have intensified the color beyond the original. By matching the hue of the chromatic reintegration to the nearby original paint, a more distinct differentiation between the original and restored areas was achieved. However, while the reintegration appeared adequate at scaffold level, it did not have the desired effect when viewed from the floor. Since the scaffold covered the entire surface of the ceiling, it was possible to assess the results of the chromatic reintegration only after its removal and the completion of photogrammetry imaging. Intensifying the blue in areas where the original paint had almost faded was necessary to achieve an integral view of the decorative design from floor level (Figure 7).

The color correction was achieved through the use of a spectrophotometer. The dark blue of the panels served as a base color to determine the correct hue, which was then applied as a neutral tone, even in the lighter or more transparent blue sections. Although the selected hue was stronger than the original light blue or gray-white areas, adjusting the saturation allowed for a uniform appearance from any viewpoint on the ceiling (Figures 7 & 8) .

Fig. 7. The photogrammetry images presented showcase the polychrome wooden ceiling of the baptistery before (left) and after the first stage (right) and second stage (bottom) of the restoration intervention. These images highlight the differences in the blue hue between the original paint and the chromatic reintegration. The use of a neutral chromatic blue color, guided by a spectrophotometer, made it possible to obtain a harmonious view of the ceiling while simultaneously establishing a clear distinction between the original paint and the restoration areas. This discrepancy in color is an important aspect to consider, as it demonstrates the challenges faced in achieving a perfect match during the restoration process (Images: Misiones Coloniales de Chihuahua A.C., Montes Treviso F., 2024).

Fig. 8 View of the beams after the color correction. Note that the same blue hue was used for the chromatic reintegration, despite the difference in the hue of the original paint (Photo: Muñoz-Alcocer,K.,2024).

The readings from the spectrophotometer were analyzed in the CIEL*a*b* color space for the 10° Supplementary Standard Observer and D65 Standard Illuminant. As reported in the *L*a**b* diagram (figure 9), the colorimetric data allowed us to confirm that the blue hue of the panels (T) has lower luminosity (L). The beam sides facing natural light (a) and those facing the interior of the room (c) presented interesting results. Although the chromatic values (a* and b*) were almost identical, it was the luminosity (L*) that differentiated these groups. The 'a' sides, closer to the window, exhibited higher L* values, while the 'c' sides had lower values. However, beams 2.c, 5.c, and 6.c showed the same L* values as the beam sides exposed to natural light (3.a, 5.a, 7.a, 8.a). This suggests that light is not the only factor influencing the hue degradation of the blue color; it may also be related to the method of application and the skill of the painter.

Finally, the use of the spectrophotometer also enabled the establishment of a homogeneous chromatic reintegration. The slight variations in hue were consistent with the original polychrome hues of the beams or panels.

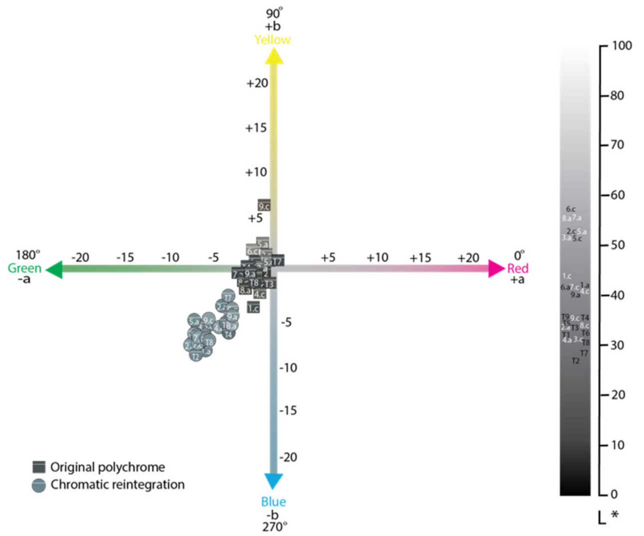


Fig. 9. Diagram of CIELAB color chart with the L a* b* resulted form the orginal paint and the chormatic reintegration (Muñoz-Alcocer,K.,2024).*

4.2. *Particular findings*

The restoration process allowed for a detailed examination of the polychrome materials and design of the ceiling, revealing the involvement of multiple artisans. While the overall design was applied using a stencil technique, the botanical elements, such as flowers and leaves, were hand-painted and outlined. Variations in the design were observed, including differences in starting points and omissions, with some areas missing black outlines, suggesting that the work may have been left unfinished (Figure 10).

The side beams also show inconsistencies, with decorative modules varying in size and shape. These imperfections, noticeable only through the restoration process, highlight the importance of such interventions for understanding the manufacturing techniques. Photogrammetry aids in observing the artwork's condition, but deep, hands-on observation during restoration provides a clearer understanding of the techniques and design applications. The restoration serves as a dialogue with the artwork, offering valuable insights into its creation.

Fig. 10. Detail of the decorative flowers on the panels. Notice the absence of black lines (Photo: Muñoz-Alcocer, K.,2024).

4.3. *Training & Community outreach*

The project focused on involving community members in the conservation of their cultural heritage, aiming to raise awareness of the Church of Santa Maria de Cuevas' historical and artistic significance. Through this, they could pass on knowledge to others in the community and future generations. In addition to conservation training, three workshops were held for local students, ranging from first grade to high school. One workshop, "How Was My Church Painted?", explored the church's artistic history and its relevance to Northern Mexico's heritage. Students participated in field visits to identify local pigments, dyes, and binders potentially used in the church's decoration, contrasting these with materials imported from central Mexico (Figure 11). They also learned the *spolvero* technique for applying decorative motifs and recreated panels using the same methods used 300 years ago to paint the church.

Community outreach included regular meetings to discuss conservation strategies, along with conferences and site visits for both locals and tourists. These efforts highlighted the church's artistic features and aimed to raise awareness of its conservation needs, fostering new perspectives on cultural tourism in Santa María de Cuevas.

Fig 11. Images of the workshop "How was painted my church? With students of Santa Maria de Cuevas schools (Photo: Munoz-Alcocer, K. Jaquez Sotelo J., & Ruiz E., 2024)

5. Conclusions

The study highlights the challenges encountered in achieving perfect color reintegration, particularly with the blue hues. Despite efforts, significant variations in color were observed, indicating the difficulty of obtaining an exact match. This underscores the inherent challenges in preserving and restoring historical artwork to its original state. Nonetheless, the study offers valuable insights into the materials, manufacturing techniques, and conservation strategies employed in the restoration of the Church of Santa María de Cuevas, contributing to the broader understanding of Spanish colonial churches in the Chihuahua region.

The chromatic reintegration technique, *sottotono*, can be difficult to apply when color hue differences are present in the original paint. In the early stages of the project, the intention was to create distinct contrasts using 'similar hue areas,' but the final result failed to achieve proper visual continuity when viewed from floor level. The use of a spectrophotometer allowed for the achievement of a neutral color by starting with the darker tones. Although the hue of the chromatic reintegration appeared more saturated in areas where the original color had faded, a consistent appearance was ultimately achieved, clarifying that the faded areas were indeed part of the original paintwork.

In addition to the technical aspects of the restoration project, this paper also highlights the importance of community engagement, workshops, and training programs. The involvement of local women in the conservation treatments proved to be a valuable experience, fostering a sense of ownership and connection to the cultural heritage of the Church of Santa María de Cuevas. Through these initiatives, the community gained a better understanding of the significance of preserving their historical artwork, and the local women acquired valuable skills in conservation techniques. This holistic approach to restoration not only contributed to the preservation of the church but also empowered the community to actively participate in the safeguarding of their cultural heritage, contributing to cultural identity processes that lead to the safeguarding of its Historical-Artistic Heritage. To this end, the community-centered approach with a gender and intergenerational perspective was considered throughout the process, which, in turn, is committed to the United Nations 2030 Development Agenda, and specifically to the Sustainable Development Goals. (SDGs), such as SDG 4 (Education), SDG 5 (Gender Equality), SDG 10 (Reducing Inequalities), SDG 11 (Sustainable Cities and Communities, whose goal 11.4 mentions the need to Safeguard Cultural Heritage and Natural), and SDG 17 (Partnerships to achieve the SDGs).

6. Conflict of interest declaration

The authors of this paper declare that there are no conflicts of interest regarding the publication of this article. No financial, personal, or other relationships with people or organizations have influenced, or could be perceived to influence, their work within the past three years. The information presented in this paper is a product of the observation and experience of the authors, and not of the conservation project itself.

7. Funding source declaration

The funding granted for the conservation project of the baptistery ceiling of Santa Maria de Cuevas was made possible by the Fiscal Stimulus for Culture and the Arts from the state of Chihuahua, EKA 2023, of the Secretary of Culture. The companies Duraplay de Parral, Interceramic, and Cofiasa supported this project by redirecting their ISR tax to carry out the conservation project. Additionally, the municipality of Dr. Belisario Dominguez contributed to the local logistics of the project and part of the salary of the working team.

8. Acknowledgment

The authors are grateful to Misiones Coloniales de Chihuahua A.C., Laboratorio de Patrimonio Histórico, and Instituto Nacional de Antropología e Historia – INAH, which have contributed to the development of this project. The funding for the conservation project was made possible thanks to the companies Interceramic, Duraplay, and Cofiasa, through the program EKA 2023 of the Secretary of Culture of the State Government of Chihuahua. Without their support, the restoration of this ceiling would not have been possible. In particular, we would like to extend our sincere thanks to the local authorities, professors, and members of the community of Santa María de Cuevas for their hospitality and support throughout the entire duration of the project.

9. Short biography of the author(s)

Karla Muñoz-Alcocer Holds a Ph.D. in Conservation and Restoration of Cultural Heritage from the Universitat Politècnica de València, Spain. Founded director of the nonprofit Misiones Coloniales de Chihuahua and LPH, the first laboratory on science conservation research of cultural heritage in Northern Mexico. Resercher at Instituto Nacional de Antropología e Historia and CONAHCYT's SNI candidate. Is the CEO of firm *4 Heritage Conservation* and professor at Tec de Monterrey Campus Chihuahua. Became a member of ICOMOS in 2022.

Ma. Luisa Vázquez de Ágredos Pascual - PhD in Geography and History, Universitat de València (UV). International PhD in Art History, Universitat Politècnica de València (PhD Program in Conservation and Restoration of Historical Heritage). Director of Heritage at the Universitat de València. Researcher and Full-Professor in the Department of Art History of this university. She is responsible for Research Projects at Laboratory of Analysis & Diagnosis of Work of Art: Conservation, Legacy, InnOvation (CLIO-ARTLab), Universitat de València.

Stephanie Estrada - Materials engineer, Technologic institute of Chihuahua. Career based in the aerospace industries as Special process engineer in Safran aerospace, failure analysis engineer in General electric, and test engineer in Honeywell aerospace. She is voluniter as lab technician at Laboratorio de Patrimonio Historico LPH, specializing in materials characterization. Art and history lover and enthusiast.

Licensing terms

References

CNA, C. N. del A. (2024) *Base de datos climatológicos - Chihuahua, Instituto Metereológico Nacional, Gobierno de Mexico*.

Doménech, A. *et al.* (2007) ‘Indigo/dehydroindigo/palygorskite complex in Maya Blue: an electrochemical approach’, *ACS Publications*, 111(12), pp. 4585–4595. doi: 10.1021/jp067369g.

Doménech, A. *et al.* (2009) ‘Maya Blue as a nanostructured polyfunctional hybrid organic–inorganic material: the need to change paradigms’, *New Journal of Chemistry*, 33(12), p. 2371.

Doménech, A. and Doménech-Carbó, M. T. (2006) ‘Chronoamperometric study of proton transfer/electron transfer in solid state electrochemistry of organic dyes’, *Journal of Solid State Electrochemistry*, 10(12), pp. 949–958. doi: 10.1007/S10008-005-0018-6.

Economía, S. De (2011) *“ Chihuahua Minero ”*. Chihuahua, Mexico.

Márquez, Z. (2004) *Misiones de Chihuahua S. XVII y XVIII*. Secretaria de Educación Pública.

Muñoz Alcocer, K. M. *et al.* (2017) ‘The narrative decorative surfaces at the spanish colonial mission church of Santa Maria de Cuevas in Nueva Vizcaya, where religion, art and science meet’, *European Journal of Science and Theology*, 13(2), pp. 135–146.

Muñoz Alcocer, K. M. (2018) *Polychrome wooden ceilings at Jesuit churches built in Nueva Vizcaya (Chihuahua, México) during the 17th and 18th centuries. Technical analysis & social awareness*. Universitat Politècnica de València. doi: 10.4995/Thesis/10251/111826.

Munoz-Alcocer, K. *et al.* (2016) ‘Santa Maria De Cuevas: A Spanish Colonial Mission Church in Nueva Vizcaya (mexico). Where Religion, Art & Science Meet’, *Esrarc 2016: 8th European Symposium on Religious Art, Restoration & Conservation*, 13(2), pp. 40–43.

Muñoz-Alcocer, K. *et al.* (2020) ‘Multi-technical approach for the characterization of polychrome decorative surfaces at Spanish Mission Churches in Nueva Vizcaya (Chihuahua, Mexico)’, *Science and Technology of Archaeological Research*, pp. 287–304. doi: 10.1080/20548923.2020.1763054.

‘Occupational Therapy Practice Framework: *Domain & Process* 2nd Edition’ (2008) *The American Journal of Occupational Therapy*, 62(6), pp. 625–683. doi: 10.5014/ajot.62.6.625.

Roca, P. M. (1979) *Spanish Jesuit churches in Mexico’s Tarahumara*. Tucson, Arizona: University of Arizona Press.

Vázquez de Agredos Pascual, M. L., Doménech Carbó, Ma. T. and Doménech Carbó, A. (2011) ‘Characterization of Maya Blue pigment in pre-classic and classic monumental architecture of the ancient pre-Columbian city of Calakmul (Campeche, Mexico’. Jurnal of Cultural Heritage, pp. 140–148.

Coloristic levels of perception of an art object in the interior space

Oksana Pylypchuk[1],

[1]*Department of Design, Kyiv National University of Construction and Architecture (KNUCA), Kyiv, Ukraine: pylypchuk.od@knuba.edu.ua*

ABSTRACT

In the context of increasing attention to the creation of a comfortable and functional-aesthetic space of various types of interiors, as well as to the visual effect that arises during their perception, the identification of effective design factors is becoming increasingly relevant. Creating a harmonious color scheme for the interior is one of the main aspects in ensuring comfortable visual perception, and consequently, favorable conditions for human life. The inclusion of coloristic works of fine art (various types of art objects) into the interior is an essential aspect in solving this issue. This article identifies one of the factors contributing to high-quality and effective design – the coloristic levels of perception of an art object in the interior space are identified, analyzed and formulated.

In the course of the study, the basic properties of color combinations are systematized and structured, based on interdisciplinary sciences, such as physics, psychology and fine arts, which influence the perception of various types of art objects in the interior. Based on them, it was determined that coloristic levels of perception from maximum, intermediate to minimum depend on a number of their main components, such as: 1) degree of color contrast (in degrees); 2) combinations and connections of colors; 3) signs of associative color scheme. As a result of the research, an innovative approach was developed, necessary in creating a specific space corresponding to a creative idea, in which the coloristic solution of art objects and the interior are in mutual harmony. The results of implementing the developed approach are demonstrated using examples of creative projects of design students from Kyiv National University of Construction and Architecture (KNUCA), Ukraine. The study demonstrates examples of completed work that confirmed the effectiveness of the developed approach in optimizing the process of choosing their color scheme, taking into account the coloristic relationship with the interior. Thanks to the use of this approach, the art objects were harmoniously integrated with the interior space, perceived as an integral part of the overall design and responding to the conceived creative idea.

Thus, the proposed approach can be useful from a theoretical point of view as a basis for studying, establishing and supplementing the various components of coloristic levels of perception. It can also serve as a tool for optimizing the process of determining the color scheme of the interior space in conjunction with various types of art objects.

KEYWORDS: Art object, Coloristics, Interior space, Color perception, Color contrast, Design.

RECEIVED 24/07/2024; **REVISED** 30/10/2024; **ACCEPTED** 04/11/2024

1. Introduction

Since ancient times, polychrome has been one of the traditional and effective means of expressing various types of fine art and interior design, which have always been an integral part of one whole space, mutually complementing each other. When creating objects of fine art and designing an interior, it was extremely important to take into account the principles of creating color combinations and their interaction in the formation of the overall color scheme (Pila and Gura, 2014).

A modern interior is a multifunctional space in which aesthetics and functionality are harmoniously combined, creating a comfortable and efficient environment for living and working (Hassanein, 2020). The use of a coloristic art object in the space provides an opportunity to create a specific mood, evoke or change an impression, and shape a particular image in the interior (Abulawi, 2023). At the same time, the perception of an art object is greatly influenced by the total volume of color space. In it, the degree of emotional impact on the viewer can change – rise or fall, depending on the overall specific color scheme used. Accordingly, the choice of the color scheme of the art object and the interior must be justified and correspond to the functional purpose and theme of the interior space, since the illogicality and unreasonableness of this factor can cause visual discomfort.

Scientists in the field of psychology and aesthetics have come to the conclusion that the main link between behavior and the coloristic interior environment is an emotional reaction (O'Connor, 2011; Pallasmaa, 2014). Goethe discovered that contrasts between different colors can enhance their impact on emotional perception (Goethe, 1840). Kandinsky, on an emotional and empirical level, sought to go beyond the field of the painting and enter the coloristic space to form it using pictorial means, inviting the viewer to try to go inside the pictorial field (Kandinsky, 1946).

Modern authors, drawing on classical works, confirm that the use of contrasting colors with a rich color scheme not only enhances the aesthetics of the space but also has a psychological impact on users, improving the clarity and functionality of the environment (Tsaqif and Hanafiah, 2020). Research shows that color, with its associative and functional-aesthetic capabilities in the interior environment, has a significant impact on various emotional reactions during perception (Ulusoy, Olgunturk and Aslanoglu, 2021; Yildirim and Hidayetoglu, 2011).

Global artistic practice reveals the potential of color to create profound emotional and visual effects, but also emphasizes the complexities and subjectivity of color perception, which depend on cultural and individual factors. By exploring how the brain works and the influence of art on artists' color palette choices, Bevil suggests that while artwork is not scientific, it is valuable for understanding how its context shapes our color perceptions and emotional responses (Bevil, 2012).

Today, it is relevant to use mathematical and information methods, as well as the use of color atlases and colorimetric systems in working with color schemes for interiors and works of fine art. Incorporating individual differences and long-term adaptation effects into atlas system models improves color perception predictions for humans. In addition, a combination of psychological experiments and information technology has led to the development of physical color characteristics that can predict color harmony with high accuracy using machine learning (Pertica *et. al.*, 2023; Smet *et. al.*, 2021; Wang *et. al.*, 2022). The use of artificial intelligence helps optimize these processes. For example, AI could be used to analyze the color statistics of original paintings and identify those that are likely to be favored by observers from different cultures. This could be useful for curators and collectors in making informed decisions about how to shape an exhibition spac (Nakauchi *et. al.*, 2022). Accordingly, innovative capabilities allow for nuances of color perception to be taken into account, can ensure high accuracy of color work and standardize results.

However, the issues of perception of art objects in the interior in the context of using the possibilities of coloristic levels remain little studied. In this regard, it becomes important to define such levels that would make a significant theoretical contribution from a scientific point of view, as well as in the field of color practices. Developing tools to analyze color relationships can improve the interior design process, allowing designers to more accurately predict and control color effects and create more harmonious and efficient spaces.

The purpose of this article is to study, analyze, systematize and establish various coloristic levels of perception of an art object in the interior space.

2. Materials and methods

2.1. *Used methods*

The research methodology included:

A method of critical analysis of modern theoretical and practical materials, which made it possible to identify interdisciplinarity in approaches to determining the coloristic role of works of art in the formation of color schemes and perception of interior space.

A method of systematization based on an integrated approach to the material being studied, which made it possible to organize and summarize the information materials used in the study in the context of the topic, and to identify the necessary components in solving the problem. The systematization results were presented in a visual structural model and table, as well as graphic images.

The experimental design method was used to confirm and record the effectiveness of using the developed approach in design decisions regarding the conditions of a specific situation. The results of the study were introduced into the applied design of educational assignments for students at the Kyiv National University of Construction and Architecture (KNUCA), Ukraine, under the guidance of the author of the study. The experiment involved undergraduate students, the total number of students was 184. The paper presents the best works that best meet the research objectives. The RGB color wheel was used to conduct the experiment. The experimental part incorporated findings from the author's previous studies, which focused on categories of artworks across various stylistic directions and the potential of the color surface of art objects to harmonize with the interior's color scheme and content (Pilipchuk and Kolomiiets, 2019; Pylypchuk and Polubok, 2022; Pylypchuk, 2024).

The method of visual analysis of completed design solutions confirmed the effectiveness of using the developed approach. This study included the best examples of developed design solutions.

The research also involved the author's many years of professional experience in the field of fine arts and design.

2.2. *The main components of the coloristic perception of interior space and art objects*

Color perception is a complex process of processing and converting information, determined by physical and psychological factors. The role of color in a person's orientation in space, the transfer of functional content, emotional and aesthetic impact, as well as the formation of favorable psychological comfort may be underestimated. The main goal of the entire aesthetic and functional system of using color schemes in space is to provide comfort and satisfaction during perception.

This research was based on fundamental work on the study of color in the aspects of its physical and psychological foundations, associative features, various possibilities of color gamuts and principles of contrast, and also took into account modern approaches in this context.

In determining the coloristic levels of perception of an art object in the interior space, the main characteristics of color were taken into account, such as: color tone – the degree of difference in spectral colors (determined by the wavelength of light reflected by the object) (Ostwald, 1969; *NASA*, 2024); color saturation – the degree of its brightness/dimness and lightness – the degree of lightness/darkness (Chevreu, 1890; Rajendran *et. al.,* 2021). It was also taken into account that achromatic colors (white, black and shades of gray) play an important role in combinations and mixing with chromatic colors (all other colors). They allow you to create contrasts, highlight accents and add depth to the color scheme (Ostwald, 1969).

An important aspect of the study was the associative capabilities of color and various emotional reactions of a person when perceiving it. For example, the Luscher color test for use in assessing the psychological state and profile of the patient (Flaviani, Plutino and Rizzi, 2023; Luscher, 1971). In this context, the associative possibilities of color in the polychromy of the general interior space were studied, with the help of which the figurative and aesthetic characteristics of the interior can be enhanced (Frieling and Auer, 1954; Itten, 1981; Yildirim and Hidayetoglu, 2011).

Accordingly, the psychological reaction (stimulating or calming) to color in a person's internal space is associated with the characteristics of color: the concept of tone, brightness, saturation, as well as associative characteristics of color – warmth/coldness of the color scheme.

3. Results

3.1. *Rationale for the Results*

The study took into account such well-known scientific facts as: complementary colors located on opposite sides of the color wheel contrast with each other, color combinations located next to each other on the color wheel have nuanced relationships, and different color schemes can evoke different associations (Itten, 1981; Ostwald, 1969).

As a result of the study, based on the analysis and structuring of the main characteristics of the coloristic relationships of the interior space and the art object, the main coloristic levels of perception were identified: maximum, intermediate and minimum.

Each level was based on the measurement of the corresponding angles, which were determined relative to the arrangement of spectral colors, the range of contrast or nuance combinations. For this purpose, the generally accepted modern color system (according to the Ostwald chromatic circle) was taken.

The result allowed us to form a visual model depicting three areas with angular ranges, each of which corresponds to a certain coloristic level of perception (Figure 1).

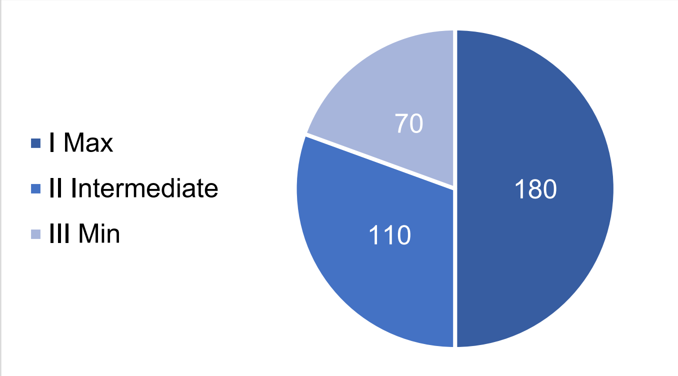


Fig. 1. Visual model of coloristic levels of perception in degrees (developed by the author)

Table 1 formulates the levels of coloristic perception, the main components of which are the degree of color contrast, the combination and connection of color schemes, as well as their associative characteristics.

№	Coloristic levels of perception	Main components of color levels		
		Degree of color contrast (in degrees)	**Combinations and connections of colors**	**Signs of associative color scheme**
I	**Max**	110°–180°	1) Chromatic; 2) Chromatic – Achromatic	Warm – Cold
II	**Intermediate**	70°–110°	1) Chromatic; 2) Chromatic + Ahromatic	1) Warm; 2) Cold; 3) Mixed
III	**Min**	<70°	1) Chromatic; 2) Chromatic + Achromati; 3) Achromatic	Neutral

Tab. 1. Coloristic levels of perception of an art object in the interior space (developed by the author).

Note to Table 1:

I. The first level of coloristic perception is Max.

- The degree of color contrast is within the range of 110°–180° color wheel. In high contrast complementary colors of the spectrum.

- Possible combinations and connections of the color scheme are based on: 1) Chromatic scale in combinations of saturated pure spectral colors and their connections with maximum color contras; 2) Chromatic scale in maximum contrast to the Achromatic scale (connection of saturated pure colors and their mixtures in contrast with whites, blacks and shades of gray in their maximum gradation).

- The associative effect of the color scheme is in opposition – Warm to Cold colors.

- Features of the first coloristic level: maximum expressiveness with pronounced contrast, active perception of the color gamut, dynamic composition, high chromatic activity, increased requirements for the balance of the color composition.

II. The second level of color perception is Intermediate.

- The degree of color contrast is within the range of 70°–110° color wheel. In the average contrast of complementary colors, or in the contrast of closely spaced colors in the spectrum.

- Possible combinations and connections of the color scheme are based on: 1) Chromatic scale in combinations of saturated pure spectral colors and their connections, but within the same color nuance; 2) Chromatic scale combined with an Achromatic scale (in combinations of medium-saturated pure colors mixed with white, black, and shades of gray in their mid-gradation).

- The associative effect of the color scheme causes a feeling of Warmth/Cold, or a mixed color scheme.

- Features of the coloristic level: average expressiveness of contrast, nuanced perception of the color gamut, average chromatic activity, not expressed dynamism in the overall visual perception, expanded capabilities in the balance of color composition.

III. The third coloristic level of perception is Min.

- The degree of color contrast is within 70° and less of the color wheel. In the convergence of related colors of the spectrum.

- Possible combinations and combinations of the color scheme are based on: 1) Chromatic scale in combinations of weakly saturated pure spectral colors and their compounds, but in color nuance; 2) Chromatic in combination with Achromatic scale (in a combination of weakly saturated pure colors mixed with white, black and shades of gray in their minimal gradation); 3) Achromatic scale (in combinations of mixed colors).

- The associative effect of the color scheme causes a feeling of Neutrality of the color scheme.

- Features of the coloristic level: lack of contrast, the color gamut is perceived in barely noticeable nuanced differences, minimal chromatic activity up to the transition to achromaticity, a feeling of staticity in the overall visual perception, limited possibilities in balancing the color composition.

3.2. *The structure of the experiment*

To verify the developed approach and the potential for practical application of the levels of coloristic perception of an art object in an interior space, an experiment was conducted. This experiment was based on the development of a design project for an interior space with a created and integrated art object. The experiment was carried out in a group of students majoring in "Interior and Equipment Design" at the Kyiv National University of Construction and Architecture (KNUCA), Ukraine, in the practical course "Interior Painting". The experiment included the simultaneous implementation of two tasks: the development of interior design and the creation of picturesque art objects in their coloristic relationship. When developing a design solution, students examined the main components of the identified levels and completed a practical task regarding the given characteristics of various levels of perception (maximum, Intermediate, minimum), which allowed them to create well-founded design solutions. It was taken into account that the main distinguishing feature of painting from other types of fine art is that the image of form and space, images and actions is constructed exclusively with the help of color. In painting, color is the main means of expression; in other types of creativity, color serves as an additional opportunity to emphasize the expressiveness of the form and content of the work.

Figures 2–4 show examples of the results obtained.

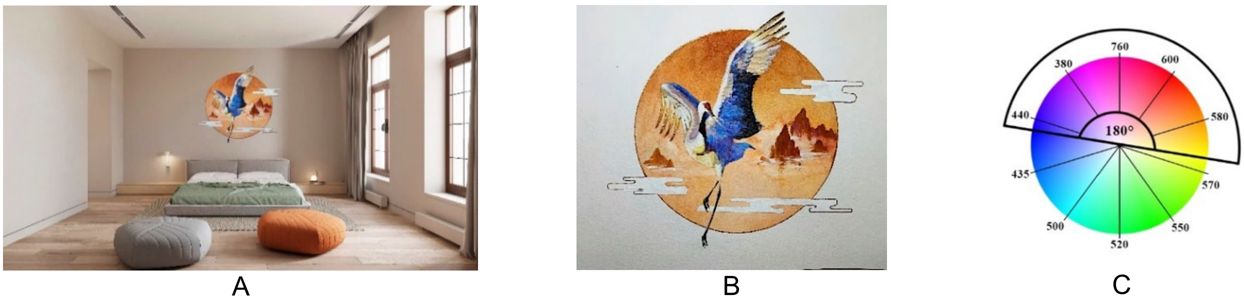


Fig. 2. Example of Max coloristic level of perception. Author Tetiana Bulba, supervisor Oksana Pylypchuk: A – visualization of bedroom design in a living space; B – painting project "Tango with clouds"; C – structural diagram of the color scheme and the degree of color contrast with the maximum coloristic level of perception. (Visual material by the author).

Note to Figure 2:

Coloristic level of perception – Max:

1) Degree of color contrast (in degrees) of the overall space of the interior and art object – 180̊, from blue to orange-yellow spectral range (wavelength approximately 430–575 nm);

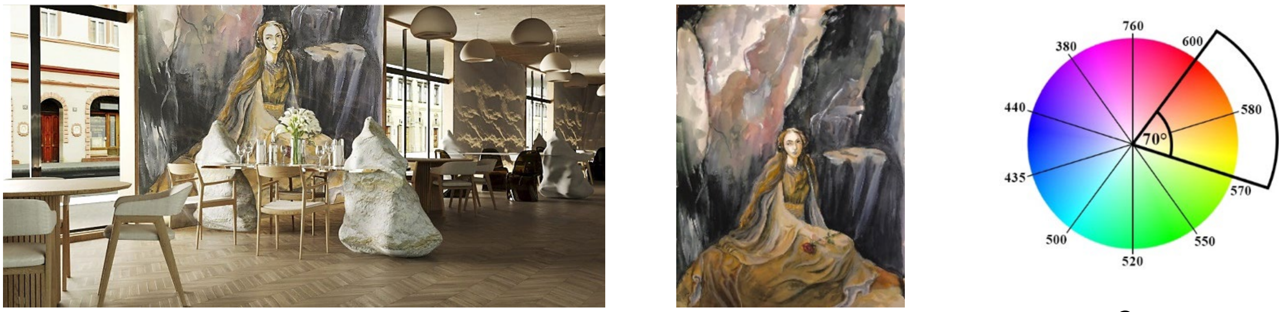
2) Chromatic in maximum contrast to the Achromatic scale of the art object and interior space;

3) Associative perception – a Warm color scheme in maximum contrast with a Cold color scheme.

The result, Figures 2(A), 2(B): the effect of expressiveness, contrasting color diversity, stability of impression, active perception of the color range, increased chromatic activity. Significant impact on the perception, emotions and visual impression of a person, taking into account the maximum contrast in the perception of color gamut, lightness and saturation, as well as the associative nature of color compounds.

Fig. 3. Example of Intermediate coloristic level of perception. Author Daria Makarchuk, supervisor Oksana Pylypchuk: A – restaurant interior design visualization; B – project of a painting panel "Melody"; C – structural diagram of the color scheme and the degree of color contrast with the Intermediate coloristic level of perception. (Visual material by the author).

Note to Figure 3:
Coloristic level of perception – Intermediate:
1) Degree of color contrast (in degrees) of the overall space of the interior and art object – 110°, from the violet-purple to the orange-yellow spectral range (wavelength approximately 400–579 nm);
2) Chromatic mixed with Achromatic scale of art object and interior space;
3) Associative perception – Warm color scheme.
The result, Figures 3(A), 3(B): a coloristic symbiosis of the artistic form with the interior space, staticity and unity of the composition with a variety of elements and forms, a sense of identity. A harmonious and balanced atmosphere, ease of perception and an emotionally balanced impression. A variety of shades in combinations with an achromatic range.



A B C

Fig. 4. Example of Min coloristic level of perception. Author Nataliia Popeta, supervisor Oksana Pylypchuk: A – cafe interior design visualization; B – project of a picturesque wall painting "Princess Marushka"; C – structural diagram of the color scheme and the degree of color contrast with the Minimum coloristic level of perception. (Visual material by the author).

Note to Figure 4:
Coloristic level of perception – Min:
1) Degree of color contrast (in degrees) of the overall space of the interior and art object – 70°, from yellow to red spectral range (wavelength approximately 570–600 nm);
2) Chromatic mixed with Achromatic scale of art object and interior space;
3) Associative perception – Neutral color scheme.

The result, Figures 4(A), 4(B): coloristic unity of the artistic form with the interior space, static composition, a sense of balance and integrity. Nuanced combinations are distinguished by subtle color differences, common color tone and neutral associative effect, similar properties, and integrity. Neutrality of the gamma, close to achromaticity in light, desaturated and muted colors, with weak color differences. The effect of ease in combining color combinations.

3.3. *Discussion*

The result of testing the developed approach showed that by using the identified levels of coloristic perception, it is possible to balance and harmonize the coloristics of the interior environment and art object, give the space a certain emotional mood and create a unique atmosphere of the visual environment, which is characterized by the presence of inherent visual associations, images, and level of comfort and the degree of harmony. Also, the results of the experimental design showed that the coloristic levels of perception identified during the study can be applied to any design solution, depending on the creative task. Accordingly, the coloristic levels of perception in the interior environment depend on the creative concept, while the color scheme becomes leading in creating a coherent space.

It is important to remember that atlas color systems continue to play a significant role in modern color design, offering certain advantages such as versatility, consistency, accuracy, and predictability. However, they also have several drawbacks: complexity of understanding, limitations in artistic expression, dependence on the device's technical features, occasional discrepancies with human perception, and labor intensity. This study proposes an innovative approach based on the use of color perception levels that can optimize the process of color selection in creative design.

However, we must not forget that the identified coloristic levels of perception, as tools of the proposed approach, are only the starting point in creative activity. Each artist has a unique sense of color, which allows him to create unique palettes and color combinations. Taking this into account, it is worth noting that coloristic levels of perception can vary depending on individual differences in perception and sensitivity to color combinations, and also depend on the conditions of the interior space (lighting, subject content and its reflexive influence, etc.).
Therefore, this issue is promising and requires further research.

4. Conclusions

As a result of the research, an innovative approach was developed, necessary in creating a specific space corresponding to a creative idea, in which the coloristic solution of art objects and the interior are in mutual harmony. The proposed approach is based on the coloristic levels of perception determined during the research and structuring: 1) maximum (with a pronounced contrast of color elements with a high impact on perception, a high level of chromaticity of color combinations and associations); 2) Intermediate (with average contrast of color elements, average impact on perception, average level of chromaticity in color combinations and associations); 3) minimal (with minimal contrast of color elements, low impact on perception, neutrality in color combinations and associations).

A visual analysis of the developed color solutions for the design of an art object integrated into the interior space allowed us to recommend the proposed approach for practical use in any works of art, regardless of style and concept. Accordingly, it can be stated that determining the necessary coloristic levels of perception of an art object in the interior space, even at the initial stages of design and creative work, can significantly increase the efficiency of the creative process.

5. Conflict of interest declaration

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

6. Funding source declaration

This research was obtained by the author thanks to scientific and teaching work at the Kyiv National University of Construction and Architecture (KNUCA), Ukraine, Faculty of Architecture, Department of Design, as well as thanks to the creative practices of the author of the study.

7. Short biography of the author(s)

Oksana Pylypchuk – Phd (Technical Sciences), Assistant professor at the Department of Design, Kyiv National University of Construction and Architecture (KNUCA). Artist-painter, author of artistic works of various types, as well as designer-decorator of interior spaces for various purposes. Research Interests: visual art, environment design, architecture.

Licensing terms

References

Abulawi, R. A. (2023) ‘The Conceptual Design Themes of Artwork in the Public Spaces of Children's Hospital’, *Civil Engineering and Architecture,* 11(5), pp. 2413–2434. Available at: https://doi.org/10.13189/cea.2023.110513.

Bevil R. C. (2012) ‘Color consilience: color through the lens of art practice, history, philosophy, and neuroscience’, *The Year in Cognitive Neuroscience,* 1251(1), pp. 77–94. Available at: https://doi.org/10.1111/j.1749-6632.2012.06470.x.

Chevreu, M. E. (1890) *The principles harmony and contrast colours, and their applications to the arts*. London: George Bell and sons.

Flaviani, G., Plutino, A. and Rizzi, A. (2023) ‘Colour and emotion: the use of the colours of Lüscher test in the artistic field’, *Colour Culture and Science*, 15(2), pp. 30–38. Available at: https://doi.org/10.23738/CCSJ.150204.

Frieling H. and Auer H. (1954) *Mench. Farbe. Raum.* München: Callwey Verlag.

Goethe, J. W. (1840) *Goethe's theory of colours*. London: J. Murray.

Hassanein, H. (2020) ‘Trends of Contemporary Art in Innovative Interior Architecture Design of Cultural Spaces’, *Cities' Identity Through Architecture and Arts*, 29(11), pp. 25–57. Available at: https://doi.org/10.1007/978-3-030-14869-0_3.

Itten, I. (1981) *Kunst der Farbe*. Rawensburg: Otto Maier.

Kandinsky, W. (1946) *On the spiritual in art*. New York: Guggenheim Foundation.

Luscher, M. (1971) *The Luscher color test.* New York: Pocket Books.

Nakauchi, S. *et al*. (2022) ‘Universality and superiority in preference for chromatic composition of art paintings’, *Scientific Reports*, 12(4294), pp. 1–12. Available at: https://doi.org/10.1038/s41598-022-08365-z.

O'Connor, Z. (2011) ‘Colour psychology and colour therapy: Caveat emptor’, *Color, Wiley,* 3(36), pp. 229–234. Available at: https://doi.org/10.1002/col.20597.

Ostwald, W. (1969) *The color primer: A basic treatise on the color system of Wilhelm Ostwald.* New York: Van Nostrand Reinhold Co.

Pallasmaa, J. (2014) 'Space, place and atmosphere. Emotion and peripherical perception in architectural experience’, *Lebenswelt*, 4, pp. 230–245. Available at: https://doi.org/10.13130/2240-9599/4202.

Pertica, A., *et al.* (2023) ‘Reflectance hyperspectral imaging for colorimetric and spectroscopic studies: the analysis of an impressionist painting’, *Color Culture and Science*, 15(2), pp. 75–82. Available at: https://doi.org/10.23738/CCSJ.150209.

Pila, J. and Gura, I. A. (2014) *Histori of interior design.* New Jersey: John Wiley & Sons, Inc.

Pilipchuk, O. and Kolomiiets, Y. (2019) 'Elaboration of main methods of using coloristics at creating the ecological interior space including artworks', *EUREKA: Art and Humanities,* 3, pp. 3–8. Available at: https://doi.org/10.21303/2504-5571.2019.00905.

Pylypchuk, O. and Polubok, A. (2022) 'The color of the surface of the Art object as a means of harmonizing the modern architectural environment', *Landscape Architecture and Art,* 21(21), 59–67. Available at: https://doi.org/10.22616/j.landarchart.2022.21.06

Pylypchuk, O. (2024) 'Research on the Categories of Fine Art Works and Their Influence on Interior Design Space'/ *Series in Arts,* 50, pp. 176–183. Available at: https://doi.org/10.31866/2410-1176.50.2024.306807

Rajendran, S. *et al.* (2021) 'Ensemble coding of color and luminance contrast', *Attention, Perception, & Psychophysics*, 83, pp. 911–924. Available at: https://doi.org/10.3758/s13414-020-02136-6.

Smet, K. A. G., Webster, M. A. and Whitehead L. A. (2021) 'Color appearance model incorporating contrast adaptation – implications for individual differences in color vision', *Color Res Appl Aug*, 46(4), pp. 759–773. Available at: https://doi.org/10.1002/col.22620.

Tsaqif, Q. and Hanafiah, U. I. M. (2020) 'Volumetric color approach as application of visual color in space zoning concept', *Jurnal dan Dialog Indonesia*, 5(1), pp. 1–9. Available at: https://doi.org/10.25124/idealog.v5i1.4034.

Ulusoy, B., Olguntürk, N. and Aslanoğlu, R. (2021) 'Pairing colours in residential architecture for different interior types', *Color Res Appl, Wiley*, 46, pp. 1079–1090. Available at: https://doi.org/10.1002/col.22640.

Visible Light (2024) '*NASA'.* Available at: https://science.nasa.gov/ems/09_visiblelight/ (Accessed: 27 May 2024).

Wang, S. *et al.* (2022) 'Attribute analysis and modeling of color harmony based on multi-color feature extraction in real-life scenes', *Frontiers in Psychology*, 13, pp. 1–15. Available at: https://doi.org/10.3389/fpsyg.2022.945951.

Yildirim, K. and Hidayetoglu, M. L. (2011) 'Effects of interior colors on mood and preference: comparisons of two living rooms', *Perceptual and Motor Skills*, 112(2), pp. 509–524. Available at: https://doi.org/10.2466/24.27.PMS.112.2.509-524.

Natural Light Aging of furniture, textile, ivory and bone in historic environments.

David Thickett[1], Boris Pretzel[2], Bhavesh Shah[1], Naomi Luxford[1]

[1] English Heritage, London, United Kingdom. David.thickett@english-heritage.org.uk

[2] Victoria and Albert Museum, London, United Kingdom (retired) / Tokyo University of the Arts, Japan (retired)

Corresponding author: David Thickett (david.thickett@english-heritage.org.uk)

ABSTRACT

This study examines the sensitivity of historical objects to long-term light exposure in UK historic houses managed by the English Heritage Trust, using real objects under natural conditions. By monitoring light levels with Elsec sensors and Hanwell Luxbug loggers, and measuring colour changes with Minolta 2600d and Ocean Optics 2000 spectrometers, the research documents the effects on textiles, wooden furniture, and bone and ivory artefacts. Objects were periodically measured over several years to document colour changes, with measurements taken after 1, 2, 3, 6, and 11 years for furniture and textiles, and after 19 years for ivories, while bone objects were measured after over 70 years of display. Bone and ivory objects were not measured periodically, but by comparing exposed and unexposed surfaces. Results indicated that light doses in most rooms were approximately 60% of the maximum values specified in light plans. Wooden furniture showed minor changes, with the most fugitive area indicating perceptible changes (ΔE_{00}≥1.5) after just over 21 years. Textiles exhibited varied colour change (ΔE_{00} ~1.7 to > 15 after 1 Mlux.h), with at least one colour on each textile showing high sensitivity, more sensitive than blue wool standard No. 1. Bone and ivory objects demonstrated relatively minor colour changes (ΔE_{00} < 1.5). Results suggested that pollutant, especially ozone concentrations, could contribute to observed colour changes but, without specific dye analysis these effects remain inconclusive. The findings highlight the challenges in managing light exposure and the need for precise, long-term measurements to develop evidence-based conservation strategies for lighting. Results suggest that current guidelines may be overly conservative for bone objects.

KEYWORDS Light management, historic houses, bone, ivory, textiles, wood, colour change, pollution

RECEIVED 02/08/2024; **REVISED** 03/10/2024; **ACCEPTED** 07/11/2024

---

1. Introduction

Determining the sensitivity of objects to light is typically accomplished by making facsimiles of the object and subjecting these to exaggerated light levels whilst monitoring the resultant colour changes (Russel and Abney 1888, Brommelle 1964, Padfield 1964, Padfield and Landi 1966). Over the last 20 years or so, techniques have been developed to allow discrete, small areas of the actual objects to be exposed and changes to be monitored on the actual object itself, either very rapidly and very high illumination (Whitmore et al. 2000, Ford and Druzik 2013) or more slowly but at high precision (Pretzel 2000, 2008, 2021), to allow light sensitivity to be measured. In contrast, this paper presents results of long term (many years) assessments of colour change of objects on display in a number of day-lit and artificially lit spaces at UK historic houses managed by English Heritage Trust. Lighting historic interiors with daylight presents numerous challenges (National Trust 2011, Mardaljevic et al. 2009, Thorn 2013, Thickett 2017). Many institutions use UV films on windows, and double blinds manually adjusted to a light plan (National Trust 2011, Thickett 2007, Pretzel 1993). Typically, these involve measuring lux levels at selected points in a room, several times a day, and adjusting blinds to bring the lux levels to the value on the plan. At English Heritage Trust, management of light levels has been achieved by training two to four people from each property. This included perception demonstrations with increasing lux levels and representative objects. Evaluation of the light monitoring from 52 locations showed they were all illuminated well under their maximum planned dose (40% under the light plan level, Thickett 2007). One instance of calibration slipping on a light meter used for the light plans at Kenwood House, London, led to a large number (over 40 in a week) of visitor complaints due to low light levels. Before increasing the light plans, research was undertaken to examine the recent fading rates of several sensitive objects in situ. Textiles and wooden objects were selected for colour measurement. The objects were measured with a hand-held spectrometer periodically for 8 years with contiguous light measurements. A further set of colour measurement was undertaken 5 years later but by this time most of the light dose measurements had been discontinued. Although the collections on display include many easel paintings and works of art on paper, these were not included in the project as the measurements would not be entirely straight forward. Different varnishes and the thick layers on paintings would introduce uncertainty as to whether changes were due to the pigment or binder or varnish. Whilst most of the furniture objects were varnished, this is most likely a shellac-based varnish and a thinner layer. All paper art is in glazed frames or occasionally showcases, substantially increasing the effort to enable accurate colorimetric measurements.

The visual impact of modern light measuring equipment means recording sensor placement is extremely limited in historic interiors. Sensors are often placed at high level on door frames, on top of painting frames. The side-lit nature of most rooms means that readings will not necessarily be representative of the light doses experienced by the contents. This added another uncertainty and provided more impetus to undertake monitoring of actual objects.

The evidence for light induced changes to bone and ivory is very limited. Colour measurements were taken on the exposed and shaded sides of a number of objects that have been displayed for over 20 years. This was complimented by a years' worth of light monitoring to enable estimation of the light dose received by the exposed surfaces over time.

Most light management strategies consider light dose to be the predominant cause of colour changes. The presence of pollutant gases such as ozone and, to a degree, nitrogen oxides, can cause dramatic colour changes in some dyes on textiles.

2. Methods and Materials

Light levels were measured using either Elsec sensors incorporated in a Meaco radiotelemetry system or free-standing Hanwell Luxbug loggers. Previous research had shown the timings used (hour averages of 10-minute readings for Meaco and averaged 1-minute readings from the Luxbug), correlated well with integrating lux meters and readings at much shorter measurement intervals (Thickett 2017). The equipment was placed very close to the object surface and at the same orientation. Fourteen light doses were estimated by exposing pieces of blue wool standards and measuring the colour change. The colour change was converted to a lux dose using the calibration published by Bullock and Saunders (1999). That method was modified to measure the same 6mm area before and after exposure to reduce errors (Thickett *et al*. 2007), Light doses from an expanded set of 85 rooms were compared to the planned doses from light plans. Discrepancy in fading rates of blue wools 1-3 have been reported for microfading and more so for lightbox aging (Ford and Korenberg 2024). Greater batch to batch variations have been observed with UV filtered daylight aging by the authors. At English heritage, each new batch of blue wool is now tested when received to produce a new calibration curve, substantially removing the contribution to uncertainty from batch variations.

Colour measurements were mainly undertaken with a Minolta 2600d instrument. The parameters are shown below, together with a summary of the equipment specifications given by the manufacturer;

- Illuminant D65 (most objects mainly day-lit).
- SCI (specular component included)
- 52mm integrating sphere
- 10nm resolution
- Range 360 to 740nm
- Spectral repeatability 0.1% (380-740nm)
- Inter instrument agreement, ΔE^*_{ab} (1976) 0.2 (MAV and SCI)

For some curved bone objects measurements were made with an Ocean Optics 2000 fibre optic spectrometer with a 1mm diameter measurement area. Parameters and instrument specifications are;

- SCI (specular component included)
- Range 300-1000nm
- Resolution 1nm
- Spectral repeatability (0.05% at 600nm, 0.1% at 450nm)

These objects were measured once only, with the exposed and unexposed surface compared. The colour differences were calculated for D65 light source and 10° observer.

For objects measured with the Minolta, the measurement points were aligned with patterns on the object, located with marked up photographs or using punched Melinex® masks (Pretzel 1992; Wilhelm and Brower 1993). The colorimeter orientation was controlled and the small area head (SAV - 6mm diameter) placed using the view port.

Colour measurements were taken after 1, 2, 3, 6 and 11 years for the furniture and textiles. Colour measurements of the exposed and unexposed surface of the 4 ivories were taken after 19 years of display. The 5 bone and single ivory object at Chesters Roman Fort were measured after more than 72 years on display.

For colours measured in the CIE system [ISO/CIE 2019] there are two (main) choices of "observer" for converting spectral power distribution of reflected (or transmitted) light to colour coordinates. The first, the so called "standard" or "2 degree" observer was agreed in 1931. The second, the so called "supplemental" or "10 degree" observer was agreed later in 1964. The choice of colour matching function is dependent on the colour variation in the visual field. In general, the 1931 observer is recommended when measuring colours of areas subtending a small angle to the eye whilst the supplemental observer is recommended where this is not the case. A brief summary of the reasons for the two choices of reference observer data is given below.

Different types of light sensitive cells are contained at the back of the eye (in the "retina"). Three classes of "cone cell" (with different maximum sensitivities, sometimes colloquially called the red, green and blue cones but more correctly referred to as the l – for long, m – for medium, and s – for short wavelength – cones) give rise to colour vision. These cones are spread in a very non-uniform manner across the retina and are heavily concentrated towards the centre of the visual field. The central part of the retina is called the fovea (approximately 1.5mm in diameter) and this is where most of the cone cells are located. At the centre of the fovea sits the foveola (approximately 0.35 mm in diameter) with the highest density of cones, where the eye performs visual tasks with the sharpest definition.

Colour sensation is derived in response to local contrasts across the mosaic of different cone cells in the retina. The three types of cone cells are not equally or similarly distributed across the retina. Indeed, the very centre of the foveola is effectively devoid of the s-cone so colour sensation from this very central high-resolution area of our eyes effectively only "dichromatic" and not "trichromatic" as we normally consider our colour vison to be. Given the complex distribution of the three classes of cone changes across the retina, it is not surprising that our colour sensation will depend on which areas of the retina are engaged with forming bits of the image.

The fovea (central portion of the field of view) covers approximately 2 degrees of view and is supposed to best be represented by the Standard Colorimetric observer. For colour analysis of complex scenes as found in many artworks, this might be considered a good representation for reference observers. However, in the course of the international adoption of this CIE standard observer, many compromises took place and mixed data sets were used so the colour matching functions and wavelength sensitivity function for this observer have been found to be somewhat wanting, especially in their short wavelength portions.

The 1964 supplemental observer colour matching functions were adopted some 30 years later and are recognized to be more consistent and experimentally better derived. A 10-degree field of view extends well beyond the foveal region, and this might be considered reasonable when assessing colour across larger objects of where variations are less detailed.

Although colour calculations will vary significantly if calculated with different observers, the effect on colour difference calculations is less pronounced – but it is of course paramount to remain consistent.

A 10° setting was used for the wood and a 2° for the intricate textile patterns. The colorimeter was regularly calibrated by the manufacturer and most measurements were taken within 3 months of such a calibration, with one of the sets taken within 6 months of calibration.

Initial trials with the Ocean Optic fibre optic spectrometer on bone surfaces indicated large errors (with five measurements the CIEDE2000 was 0.8 with uncertainty estimated at ± 3.5!) with manual positioning. A system with a clamp stand, stable lab jack, Zaber AXR X-Y automatic stage and Acuity AR 600 laser displacement sensor was used to accurately position the fibre optic head 2mm above the surface with an accuracy of 40μm. For the same bone object this approach determined a CIEDE2000 of 0.72 with a standard deviation of 0.07. This uncertainty includes any contributions from positioning error.

The objects measured are described in Table 1, which also gives the number of different areas measured and the total number of measurements (the product of the number of areas and the number of replicate measurements at each area) for each object.

Object	Location (property)	Room	Material	Col	Meas
A/Travelling Chest	Ranger's House	Introduction Room	Wood	3	15
B/Chair	Marble Hill House	Great Hall	Wood	1	5
C/Chest	Kenwood House	Housekeepers Room	Wood	3	15
D/Door	Kenwood House	Dining Room	Wood	1	5
E/Carpet	Osborne House	Council Room	Silk	13	39
F/Carpet	Audley End House	Saloon	Wool	4	8
G/ State Bed (bedspread)	Audley End House	Neville bedroom	Cotton	4	8
H/Banner	Audley End House	Great Hall	Cotton	3	6
J/Pin Open Head*	Chesters Roman Fort	Main Room Bone, Jet and Shale Case	Bone	1	10
K/Comb	Chesters Roman Fort		Bone	1	10
L/Plaque	Chesters Roman Fort		Bone	1	10
M/Brush*	Chesters Roman Fort		Bone	1	18
N/Textile Threader*	Chesters Roman Fort		Bone	1	10
O/Crozier Head	Battle Abbey	Inner Room Abbots Case	Walrus Ivory	1	16
P/Large Plaque	Ranger's House	Red Evocation Centre Case	Elephant Ivory	1	16
Q/Medium Plaque	Ranger's House		Elephant Ivory	1	16
R/Round Plaque	Ranger's House		Elephant Ivory	1	16

Tab. 1.: Objects used in this study, together with their location, material type, number of distinct colours measured ("Col"), and total number of colour measurements for each object ("Meas" – the product of number of areas and number of replicates). All colour measurements except for objects marked with an asterisk (*) were performed with a Konica Minolta CM2600d hand held spectrometer; objects marked with an asterisk were measured using an Ocean Optics 2000 spectrometer. The leading letter before each object is an arbitrarily (alphabetic in order of listing in the table) letter to aid identification in subsequent sections and tables.

Ozone and nitrogen dioxide were measured in the rooms containing the objects with diffusion tubes provided by Gradko Ltd. Measurements were taken for four-week periods determined likely to be the periods with maximum values either from previous measurements or results from the nearest automated continuous monitoring network station. Additionally, the ozone concentrations were measured monthly in the Great Hall at Audley End House for 12 months to produce an accurate annual dose figure. This location was selected as previous measurements had shown Audley End House to have the highest ozone concentrations of the properties considered. The Great Hall was thought likely to be most effected of the three rooms by pollutant infiltration; due to its large windows, proximity to the entrance door and lowest surface area to volume ratio.

3. Results and Discussion

3.1. *Measured light exposure*

The measured and planned light exposures for 85 rooms are shown in Figure 1.

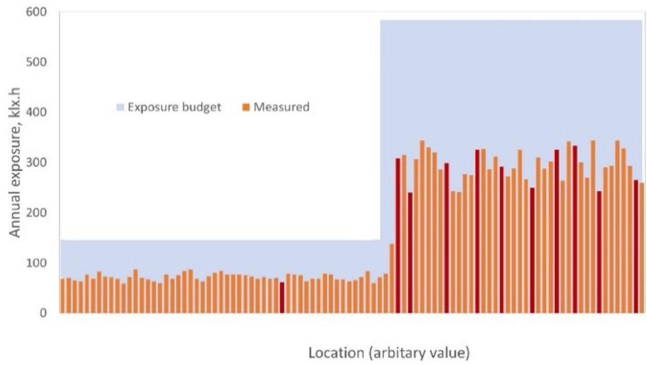


Fig. 1.: The measured and planned annual light exposure for 85 rooms. The dose specified by the light plan indicated by the light blue shaded areas for each location. Red bars are estimated exposures calculated from exposed blue wools; orange bars are calculated exposure using electronic monitors.

As can be seen, the results reflected the previous study and the measured doses are only approximately 60% of the maximum doses allowed for in the light plans.

3.2. *Fading of Furniture*

The discoloration of selected wooden furniture objects is shown in Figure 2. For each object, several (five) areas in each colour range were measured. For simplicity, only results for the fastest changing point in each colour are shown, as these will dominate the change in visual appearance for that object.

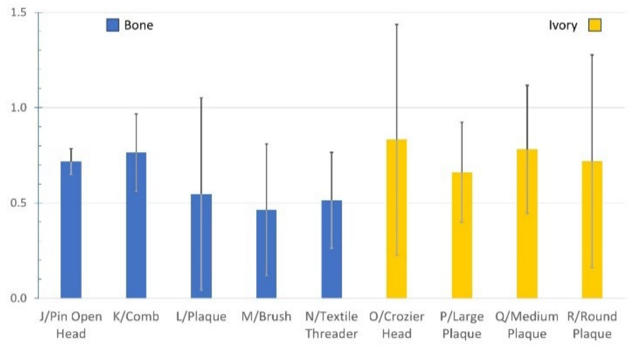


Fig. 2. : Colour changes versus light exposure for the area showing the largest colour change for four selected furniture objects. Uncertainty is estimated to be approximately 0.25 CIEDE2000 units.

The most reactive area, the black inlay on the travelling chest (A), indicates a perceptible change (*PC*, determined to be a CIEDE2000 colour change of 1.5) (Ashley-Smith et al., 2002) after just over 21 years. Terms such as 'just noticeable change' (j.n.c.) are frequently used by authors, but usually without experimental verification (e.g. Colby 1992; Derbyshire and Ashley-Smith 1999). The term *Perceptible Change* (*PC*) was introduced by Asheley-Smith and co-authors to distinguish their experimentally determined 50% likelihood of a colour difference being detected by trained observers (professional conservators) under ideal conditions (1000 lux illuminance, high colour rendering light source with 3000K colour temperature, neutral grey background with 20% reflectance) (Pretzel 2008). As luck would have it, the PC equated to a colour change approximately equal to grey scale 4 (expressed in CIEDE2000 units) and this is (typically) the value chosen for a j.n.c. The fading rate measured falls between two quoted time periods (10 and 30) years in the recommendations from Rijksdienst voor het Cultureel Erfgoed (RCE) (Rijksdienst voor het Cultureel Erfgoed 2016).

Unfortunately, an archiving error meant not all the underlying L*a*b* values were available for statistical analysis. The resultant colour differences however, were properly archived and are shown in Figure 2. In the absence of the underlying data, no formal uncertainty analysis can be undertaken at present, The uncertainty has been extimated at ± 0.25 CIEDE2000, in line with the uncertainty estimates given by Bullock and Saunders (1999) (albeit that their measurements were made using a tristimulus colorimeter rather than hand-held spectrometer and results were expressed in CIE94 colour difference, not CIEDE2000).

3.3. *Fading of textile*

The most affected and least affected colour from each textile is shown in Figure 3. Selecting the most and least rapidly changing colours on each object emphasizes the degree of differential change, as well as highlighting the most significant changes that will dominate the change in visual appearance.

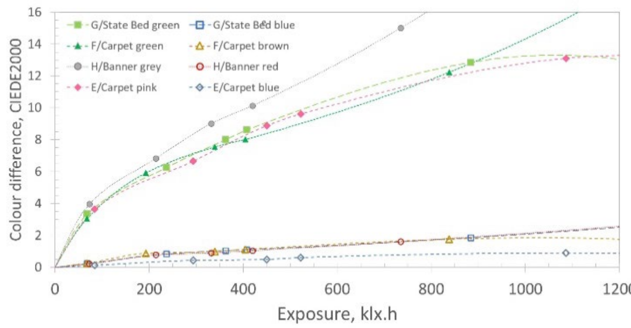


Fig. 3. Colour change on natural exposure of four textiles. Highest and lowest reactivity colour from the numerous colours measured is shown. Please note differences in scale compared to figure 2: the light levels for these objects are controlled to lower values, giving lower overall dose.

Uncertainties for this dataset were estimated at ± 0.4 CIEDE2000, based on the Bullock estimates, and considering the variable nature of the surface for embroidery (State Bed G and Banner H), and the effect of the pile on the two carpets (E an F – though, both carpets were selected as ones with no public access and site staff avoided the measurement areas).

Each textile had a number of low reactivity colours, generally changing at a rate reaching 1 PC (ΔE_{00} = 1.5) after approximately 650 ± 300 klx.h (Carpet F) to 680 ± 200 klx.h (Banner H) exposure. This falls between blue wool 2 and blue wool 1 on the blue wool equivalence scale (blue wool data from Bullock and Saunders 1999, recalculated to CIEDE200, and HERIE). One object (Carpet E) had a significantly more stable low reactivity colour, fading to 1 PC after approximately 2.3 ± 0.8 Mlx.h, putting the rating to between blue wool 2 -3 (Bullock and Saunders) or blue wool 3 (HERIE). All of the textiles had at least one highly responsive area, fading by 1 PC after only 23 ± 6 klx.h ((Banner H) to 30 ± 8 klx.h (Carpet F). These areas all remain significantly more reactive than blue wool 1 and the textile objects might therefore typically be categorized as vulnerable and not recommended for long-term display (Derbyshire et al. 2002).

The variability in light fastness of different textile dyes and colours has been reported in a number previous surveys (Padfield 1964, Padfield and Landi 1966, HERIE). Historic house collections rarely include significant reserve material for rotation and historical precedence limits the ability to change an object's location, so there is an acceptance that objects will undergo change at faster rates than might be accepted for other heritage institutions. Nevertheless, the continued high reactivity observed for the fastest changing areas on the textiles is surprising, given the long periods for which the objects have been on display. The fastest change is occurring in a grey area in the Banner (H). This has been on display only since 2002, before that having been kept in dark storage, so the high sensitivity is perhaps less surprising, given the limited historical exposure, for this object.

3.4. *Alteration of bone and ivory*

Results are shown in Figure 4.

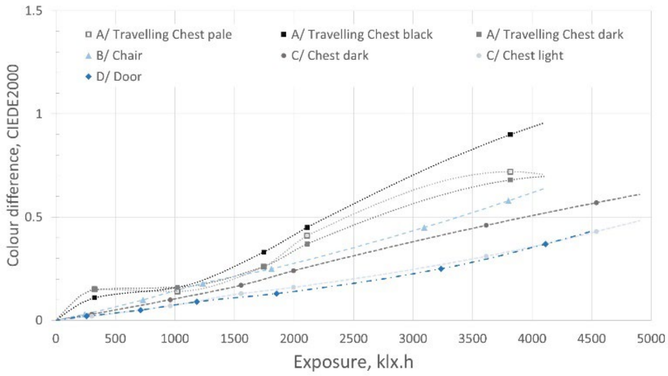


Fig. 4: Colour difference between exposed and unexposed face for ivory (in yellow) and bone (in blue) objects. NB although the colour changes shown are all of roughly the same magnitude, the ivory objects are estimated to have received roughly only 8 % (15% for the Crozier Head P) of the dose estimated to have been received by the bone objects.

For these objects, data for all five or eight repeat measurements at each point were available, so uncertainties in the colour differences were estimated by propagating variance in the CIELAB data through to the CIEDE2000 colour difference formula. The graphs show error bars equal to the calculated standard deviation. The uncertainties are large compared to the colour difference between the surfaces but the uncertainty was also calculated using the tristimulus data rather than the derived CIELAB coordinates. As both methods gave convergent results, the uncertainty estimates are considered robust. For further details the procedures used and of the nature and propagation of uncertainty in colour difference computation, see Pretzel et al. (forthcoming).

All colour changes for these objects are relatively small given the exposure periods, with none of them reaching 1 PC.

Table 2 shows the colour change versus accumulated exposure data plotted in Figure 4, together with a rough (linear) estimate of the years of exposure that might result in 1 PC.

	Colour change, ΔE_{00}	Light exposure, Mlx.h			Estimate of years to 1 *PC*	Material
		Measured over 1 year	Estimated total exposure	Estimate of dose to 1 *PC*		
J/Pin open head	0.72 ± 0.07	1.225	88.21	190 ± 20	151 ± 14	bone
K/Comb	0.8 ± 0.2	1.225	88.21	170 ± 50	140 ± 40	bone
L/Plaque	0.5 ± 0.5	1.225	88.21	240 ± 220	200 ± 180	bone
M/Brush	0.5 ± 0.3	1.225	88.21	290 ± 210	230 ± 170	bone
N/Textile threader	0.5 ± 0.3	1.225	88.21	260 ± 130	210 ± 100	bone
O/Large plaque	0.7 ± 0.3	0.096	6.92	4 ± 2	43 ± 17	Ivory
P/Crozier head	0.8 ± 0.6	0.181	13.04	8 ± 6	40 ± 30	Ivory
Q/Medium plaque	0.8 ± 0.3	0.096	6.92	4 ± 2	36 ± 16	Ivory
R/Round plaque	0.7 ± 0.6	0.096	6.92	4 ± 3	40 ± 30	ivory

Tab. 2.: Colour difference between exposed and unexposed surfaces of selected bone and ivory objects, together with measured annual exposure, estimated total exposure and a rough (linear) estimate of time at current exposure resulting in a colour difference of 1 PC.

The bone objects were exhibited at Chesters Roman Fort (see Table 1). The estimated light doses at Chesters are subject to large uncertainty as the exact exposure period can only roughly be estimated. A 1950s photograph shows the objects in place at that date, but the museum opened in the 1920s. Furthermore, there have been changes to the fabric of the building with a yellow glass skylight being replaced with clear glass. It is also not given that the two surfaces were the same colour to begin with. Nonetheless, the colour difference between the exposed surface and the unexposed is remarkedly small and much less than anticipated from several standard recommendations. RCE (Rijksdienst voor het Cultureel Erfgoed 2016) rate bone as sensitive with a limiting exposure of 10Mlx.h causing a visible change. The Canadian Conservation Institute (CCI) (Canadian Conservation Institute 2010) recommend that bone is illuminated at up to 150lux, limiting annual exposure to 440klx.h, but they do not give any indication of how quickly changes might become visible under this illumination level. The British Standards Institution (BSI) (British Standards Institution 2014) and CIE (2004) rate bone as low sensitivity or low responsivity (respectively). CIE giving an exposure of 300 – 1100 Mlx.h in uv free light for a "noticeable fade". BSI do not give an exposure resulting in visible changes but recommend a maximum annual exposure of 600 klx.h for this class of objects. Our results would rate bone as medium to low responsivity under the CIE classification, with a limiting exposure to 1 PC ranging from approximately 100 to 400 Mlx.h.

The ivory objects are on display at Rangers House and Battle Abbey. The light exposures at Ranger's House and

Battle Abbey can be estimated with a much smaller uncertainty. Our results for ivory objects fall in to the highly responsive under the CIE classification, with limiting exposure to 1 PC estimated to be 4 ± 3 Mlx.h. CCI (Canadian Conservation Institute 2010), BSI (British Standards Institution 2014) and CIE (2004) put ivory and bone in the same classification, with BSI and CIE rating them as low sensitivity or low responsivity (respectively) (and CIE rating their limiting exposure as 300 – 1100 Mlx.h). Derbyshire and Ashley-Smith (1999) rate portrait miniatures on ivory as sensitive and Derbyshire et al (2002) indicate a limiting exposure of 1.8 Mlx.h for this category. RCE suggests 1 j.n.c. in 1 Mlx.h (Rijksdienst voor het Cultureel Erfgoed 2006).

The rates of change of colour with exposure for ivory objects determined in this study are somewhat lower than the limiting rates indicated by RCE or Derbyshire et al. but are significantly faster than the rate indicated in the CIE document. In any case, this is a very small sample set and measurements of more objects would be required to produce concrete recommendations.

3.5. *Pollution*

The results of the pollution measurements are shown in Table 3.

Property	Room	Ozone		Nitrogen dioxide	
		Date (d/m)	Conc (ppb)	Date (d/m)	Conc (ppb)
Ranger's House	Introduction Room	3/4 - 1/5	2.5 ± 0.38	2/5 - 1/6	9.9 ± 1.98
Marble Hill House	Great Hall	3/4 - 1/5	1.8 ± 0.27	2/5 - 1/6	12.5 ± 2.50
Kenwood House	Housekeepers Room	1/4 - 31/5	3.6 ± 0.54	3/5 - 2/6	10.3 ± 2.06
Kenwood House	Dining Room	1/4 - 31/5	4.7 ± 0.70	3/5 - 2/6	11.4 ± 2.28
Osborne House	Council Room	14/4 - 13/5	11.1 ± 1.66	19/2 - 20/3	3.6 ± 0.72
Osborne House	Bedchamber	14/4 - 13/5	9.7 ± 1.45	19/2 - 20/3	2.9 ± 0.58
Audley End House	Saloon	5/7 - 3/8	11.3 ± 1.70	12/1 - 9/2	2.8 ± 0.56
Audley End House	Neville Bedroom	5/7 - 3/8	12.4 ± 1.86	12/1 - 9/2	2.5 ± 0.50
Audley End House	Great Hall	5/7 - 3/8	13.1 ± 1.96	12/1 - 9/2	3.2 ± 0.64

Tab. 3.: Ozone and nitrogen dioxide concentrations measured at the expected highest concentration periods for selected locations.

The concentrations measured are comparable to other data reported (Tetreault 2003, Kadokura et al. 1988). The rural properties (Osborne House, Audley End House) have higher ozone and lower nitrogen dioxide concentrations. Whilst the urban properties (Ranger's House, Marble Hill House and Kenwood House) have higher nitrogen dioxide (probably from traffic) and lower ozone concentrations. (Rozbicka and Rozbicka 2014). The annual dose of ozone in the Great Hall at Audley End house was determined to be 2954 ppb.day.

Unfortunately, most of the published data impacts of pollution impact on European natural dyes (28) is testing on paper (Whitmore and Cass, 1988 and 1989, Tetreault 2003) and the dyes present on the textiles were not analysed. Taking the highest values (worst case), 13.1ppb of ozone in Audley End Great Hall and applying that concentration value for 12 months would give an annual dose of 4781 ppb.day of ozone. Similarly for nitrogen dioxide the highest monthly concentration is 12.5 ppb (Marble Hill Great Hall), giving a worst-case scenario of 4562ppb days (ppb.day) nitrogen dioxide if present at those concentrations throughout the year. This calculation scales up the dose measured over 30 days to 365 days. The actual measured annual ozone dose (sum of 12 approximately monthly measurements) in the Great Hall was just under 64% of the estimated, worse case dose. For the most sensitive reported dyes, these doses would generate colour changes of 8.54, 13.66 and 27.32 for ozone (Whitmore and Cass 1988). and 0.33 and 0.22 for nitrogen dioxide (Whitmore and Cass 1989) over the 15-year measurement period. These values are much higher for the ozone than those measured in this work. The potential maximum effect of nitrogen dioxide is under 20% of the largest colour changes measurements. These estimates indicate it is important to consider pollution as a potential cause of colour change.

One issue with pollution measurement for cultural heritage is the lack of a method to measure long term doses. Whilst diffusion tubes are convenient and reasonably priced, the variability in concentrations across a year means 12 measurements would be required to assess an accurate dose, which greatly increases both cost and effort needed.

4. Conclusions

Light doses in these historic houses remain substantially below the anticipated and planned lighting budgets, suggesting that there is some flexibility to change the lighting designs. This will be particularly beneficial in any spaces that are regularly perceived by the public as gloomy or underlit. However, the colours on the textile objects measured should all be considered highly responsive (following the CIE classification) or vulnerable to sensitive under the V&A scheme (Derbyshire et al. 2002)

Long term measurements have shown only small colour changes (ΔE_{00}<1.5) for furniture, ivory, and bone. Bone objects, in particular, seem less sensitive than indicated by most schemes (but agree with the classification in CIE 2004).

From this data, for these specific objects at least, it appears that the lack of underpinning data has indeed possibly led to over-prescriptive guidelines for bone. The monitored textile objects, however, still have highly sensitive areas.

The verification of the fading rates, together with the relatively low actual average annual exposures, suggest light levels can be increased in some areas if needs be to improve the visual aspects of the situations, although any such change will need careful management and monitoring. However, textile objects may be already be fading at faster than anticipated rates even with the lower-than-expected annual light doses.

The measured ozone concentrations could be contributing to the colour changes observed. Without analysis of the dyes present, which was beyond the scope of this work, the changes are hypothetical. One issue with pollution measurement for cultural heritage is the lack of a method to measure long term doses economically.

This long term, natural ageing measurement approach has been extremely useful, but issues with long term calibration and uncertainty due to repositioning need addressing. Good inter-instrument repeatability is needed for robust results. A reasonable number of replicates are required for systematic and robust uncertainty analysis, which is particularly important for determining small colour changes with confidence. Five to eight replicate measurements (where available) appeared to produce colour difference and variance estimates that remained consistent regardless of whether the computation was carried out directly from the XYZ co-ordinates or using the derived CIELAB variables.

The early training courses for English Heritage staff appeared to have engendered over precautious attitudes to lighting levels and led to doses significantly under those anticipated in light plans. The training has been modified to reduce areas perceived by visitors as under luminated.

The utility of long-term measurements under actual exposure conditions has been demonstrated. Long term stability of the spectrometer and accurate repositioning for measurements are critical. These did not detract from usefulness or credibility of the data.

5. Conflict of interest declaration

The authors declare no conflicts of interest.

6. Funding source declaration

The automated stage, controller and laser displacement sensor were purchased with a CapCo World Class laboratories grant from UKRI.

7. Short biography of the author(s)

David Thickett (ORCID 0000-0001-9532-1517) is the senior conservation scientist at English Heritage. He specialises in the study of environmental preventive conservation and object response. He has a particular interest in pollution and his recent research has focused on epidemiology, sustainability, damage functions, acoustic emission, non-invasive testing and showcases. David is a directory board member of the Infra-red and Raman Users Group; UK Expert to CEN TC346, European conservation standards and editorial board member of Heritage Science.

Boris Pretzel (ORCID 0009-0008-8388-2737) was Materials Scientist (1989-2011) then Head of Science (2011-2021) at London's V&A, then invited Professor of Conservation Science, Tokyo University of the Arts, 2022-2024. His research interests include the perception and measurement of colour, and the propagation of uncertainty in measurements. He is European chair, former president, and founding directory board member of the Infrared and Raman Users Group, a Trustee of the National Heritage Science Forum, a Chartered Physicist, a Chartered Scientist, and Fellow of IIC.

Bhavesh Shah (ORCID 0000-0001-8673-0589) is a Conservation Scientist at English Heritage. His research primarily focuses on using environmental monitoring and data science to support preventive conservation and object preservation. He has an interest in machine learning, sustainability, lighting and colour change. Bhavesh is a member of the Royal Society of Chemistry and a member of the Institute of Conservation UK.

Naomi Luxford (ORCID 0000-0002-7751-7783) is a Conservation Scientist at English Heritage, working on environmental control and monitoring, including display cases, heating systems and light control. With an emphasis on how display requirements and indoor environmental conditions relate to building performance, particularly in historic buildings. Her research focuses on how materials in collections deteriorate as a result of the environmental conditions around them.

Licensing terms

References

Ashley-Smith, J, Derbyshire, A., and Pretzel, B (2002) "The continuing development of a practical lighting policy for works of art on paper and other object types at the Victoria and Albert Museum" in Bridgland, J, (ed.), Preprints of 13th triennial meeting of the ICOM Committee for Conservation Rio de Janeiro. London: James & James, pp3 - 8.

Billmeyer, F. W. (1983) "Color Science: Concepts and Methods, Quantitative Data and Formulae, 2nd ed., by Gunter Wyszecki and W. S. Stiles, John Wiley and Sons, New York, 1982, 950 pp. Color Research & Application, 8(4), pp. 262–263. doi: 10.1002/col.5080080421.

British Standards Institution (2014) PD CEN/TS 16163 Conservation of Cultural Heritage — Guidelines and procedures for choosing appropriate lighting for indoor exhibitions. BSI Gunnersbury.

Brommelle, N. S. (1964) "The Russell and Abney report on the action of light on water colours," Studies in Conservation, 9(4), p. 140. doi: 10.2307/1505213.

Bullock L. and Saunders, D. (1999). Measurement of cumulative exposure using blue wool standards, Preprints of 12th Meeting of ICOM-CC, Lyon, 21-26.

Canadian Conservation Institution. (2010) Care of ivory, bone and antler. Notes 6/1

Cannon-Brookes, S. and Perry, M. (1996), Daylighting dosage prediction for side-lit interiors in museums, galleries and historic buildings. In: Bridgland, J. (1999) ICOM 12th Triennial Meeting Lyon. Maney - Heritage, p. 920.

CIE Publications - CIE 157 (2004), Control of Damage to Museum Objects by Optical Radiation.

Colby, K. (1992) "A Suggested Exhibition /Exposure Policy for Works of Art on Paper", Journal of the International Institute for Conservation, Canadian Group **17**: 3-11

Derbyshire, A., and Ashley-Smith, J. (1999) "A proposed practical lighting policy for works of art on paper at the V&A." In Bridgland, J. (ed.), Preprints of the 12 ICOM-CC Triennial Meeting Lyon. London: James & James, pp. 38 – 41.

Eibl, M. (2015), The development of the museum building from the perspective of preventive conservation, PhD, Technical University of Munich.

Ford, B. and Durzi, J. (2013) "Microfading: the state of the art for natural history collections," in Collection forum, pp. 54–71.

Ford, B. and Korenberg, C. (2024) Manufacturing Variations in ISO Blue Wool Fading Standards under Microfading Exposure Conditions. Studies in Conservation, 69 (3), pp. 209–220https://doi.org/10.1080/00393630.2023.2184555

HERIE, Radiation module. Available at: https://www.herie.pl/RadiationCalculations/single (Accessed: 25 July 2024).

ISO/CIE 2019. ISO/CIE 11664-1:2019 - Colorimetry — Part 1: CIE standard colorimetric observers (no date). Available at: https://www.iso.org/standard/74164.html (Accessed: July 19, 2024).

Katakura, T. et al. (1988) "Concentration of nitrogen dioxide in the museum environment and its effects on the fading of dyed fabrics," Studies in Conservation, 33(1), pp. 87–89. doi: 10.1179/sic.1988.33.1.87.

Lloyd, H. (2002), Strategies for visitor management at National trust properties. In: Postprints of 4th European Commission Conference, Research for protection, conservation and enhancement of cultural heritage, Strasburg 2000. Luxemburg office for official publications of the European communities, pp.166-171.

Mardaljevic, J., Painter, B. and Andersen, M. (2009) "Transmission illuminance proxy HDR imaging: A new technique to quantify luminous flux," Lighting Research & Technology, 41(1), pp. 27–49. doi: 10.1177/1477153508097670.

National Trust (2011), The National Trust Manual of Housekeeping, Butterworths Heinemann, Oxford.

Padfield, T. (1964) "The rate of fading of natural dyes," Studies in Conservation, 9(sup1), pp. 126–132. doi: 10.1179/sic.1964.s022.

Padfield, T. and Landi, S. (1966) "The Light-Fastness of the Natural Dyes," Studies in Conservation, 11(4), p. 181. doi: 10.2307/1505361.

Pretzel, B. (1992) "The Analysis of Comparative Colour Changes Occurring in a set of 19th Century Albumen Photographs by Lady Hawarden", In: Conference Proceedings: The Imperfect Image - Photographs, their past, present and future, Windermere, 1992, The Centre for Photographic Conservation, London, pp. 165 - 181, Plate 9, ill. ISBN 0952139308

Pretzel, B. (1993) "Practical Preventive Conservation." In Norman Tennant (editor) Conservation Science in the UK. Preprints of the Glasgow meeting, London: James & James: 106-110

Pretzel, B. (2000) "Determining the colour fastness of the Bullerswood carpet," Studies in Conservation, 45(sup1), pp. 150–154. doi: 10.1179/sic.2000.45.Supplement-1.150.

Pretzel, B. (2008) "Now you see it, now you don't: lighting decisions for the Ardabil carpet based on the probability of visual perception and rates of fading," in Bridgland, J. (ed.), Preprints of the 15th triennial meeting of the ICOM Committee for Conservation in New Delhi, New Delhi: Allied Publishers Pvt. Ltd., pp. 751–757.

Pretzel, B. (2021) "Surface alteration of Japanese lacquers on exposure to (UV-free) light," in Bridgland, J. (ed) Transcending Boundaries: Integrated Approaches to Conservation. Proceedings of the ICOM-CC 19th Triennial Conference, Beijing, China. Paris: ICOM-CC, pp. 17–21.

Pretzel, B., Tsukada, M, and Ogura, S. forthcoming. "On the nature and propagation of uncertainties in colour difference measurement".

Rijksdienst voor het Cultureel Erfgoed (2016) Limiting light damage in museum objects: Light Lines

Rozbicki, T and Rozbicki, K (2014) Spatiotemporal variations of tropospheric ozone concentrations in the Warsaw Agglomeration (Poland) Annals of Warsaw University of Life Sciences – SGGW Land Reclamation No 46 (3), pp. 247–261

Ruess, M.; Scott, G. and MacKinnon, F. (2013), Conservation of exhibitions: making a maintenance programme. In: Preprints of ICOMCC 14th Triennial Meeting, Lisbon, pp.693-699.

Russell, W. J. and de Wiveleslie Abney, W. (1888) Report to the Science and Art Department of the Committee of Council on Education on the Action of Light on Water Colours: Presented to Both Houses of Parliament by Command of Her Majesty. HM Stationery Office.

Tetreault, J. (2003) Airborne Pollutants in Museums, Galleries and Archives: Risk Assessment, Control Strategies and Preservation Management.

Thorn, A. (2013), Predicting the solar impact of the restored glazing regime of the Domed Reading Room, State Library of Victoria. In: Preprints of ICOM-CC 14th Triennial Meeting, Lisbon, pp.716-725.

Thickett, D.; Rhee, S. and Lambarth, S. (2007), Libraries and archives in historic buildings, in Museum Microclimates, Copenhagen: Bogtryk, Hvidovre, pp.145-156.

Thickett D. (2017), Managing natural light in historic properties. In: Homen P.M. (ed) *Lights on… Cultural Heritage and Museums*, LabCR/FLUP, Porto 2017, pp 245-264.

Weschler, C. J., Shields H., Naik, D.V., (1989). Indoor ozone exposures. Journal of the Air and Waste Management Association, 39, 1562-1568.

Wilhelm, H. and Brower. C. (1993) The Permanence and Care of Color Photographs: Traditional and Digital Color Prints, Color Negatives, Slides, and Motion Pictures. Reservation Publishing Company: Grinnell, USA ; http://www.wilhelm-research.com/book_toc.html

Whitmore, P. M. and Cass, G. R. (1988) "The ozone fading of traditional Japanese colorants," Studies in Conservation, 33(1), pp. 29–40. doi: 10.1179/sic.1988.33.1.29.

Whitmore, P. M. and Cass, G. R. (1989) "The fading of artists' colorants by exposure to atmospheric nitrogen dioxide," Studies in Conservation, 34(2), pp. 85–97. doi: 10.1179/sic.1989.34.2.85.

Whitmore, P. M., Bailie, C. and Connors, S. A. (2000) "Micro-fading tests to predict the result of exhibition: progress and prospects," Studies in Conservation, 45(sup1), pp. 200–205. doi: 10.1179/sic.2000.45.Supplement-1.200.

Queer Futures, Violet Futures: Queer Modernity Symbolism of Violet in West Culture

Kévin Bideaux[1,2]

[1] Laboratoire d'Études sur le Genre et la Sexualité (LEGS, UMR8238), University of Paris 8, France. hello@roseincorporated.net

[2] Centre Français de la couleur (CFC), France.

Corresponding author: Kévin Bideaux (hello@roseincorporated.net)

ABSTRACT

The history of arts, gender studies, and queer theories is brought together to analyze the artistic, cultural, and political uses of violet since the discovery of mauvein by William H. Perkin in 1856. Looking back over the last 150 years of violet's history, the aim is to highlight how this color has linked modernity and queerness since the late 19th century, when violet tones became a defining characteristic of fin-de-siècle fashion, painting, and literature. Violet has also long been associated with feminist and queer movements in Europe and North America, from the Suffragettes' emblem to the non-binary pride flag. Beyond the visible spectrum, ultraviolet light can serve as a metaphor for a 'beyond of gender', referring to the dissolution of feminine/masculine and homo-/heterosexual binaries. Could violet be the color of the future? And is that future inherently queer?

KEYWORDS Violet, Queer, Modernity, Colour Symbolism, Synthetic Colorants

RECEIVED 24/07/2024; **REVISED** 17/10/2024; **ACCEPTED** 02/11/2024

1. Introduction: A Modern Take on Violet

In 1856, the discovery of the synthetic dye mauveine by British chemistry student William Henry Perkin marked a major turning point in the history of violet [1]. Until then, its production had been difficult and expensive; however, it was now possible to produce it inexpensively and quantitatively, sparking a veritable trend in fashion and painting at the end of the 19th century. As a result, violet began to be used as a means through which these groups were stigmatised, who, through reappropriation, also embraced the colour as a cryptic queer emblem. The turn of the 20th century also witnessed feminist struggles for suffrage, with violet emerging as a significant emblem for one of the most renowned suffrage movements: the Suffragettes. A few decades later, violet became closely linked to queer struggles, and by the 2000s, it had become synonymous with transgender and non-binary identities, representing a desire to transcend the binaries of masculinity and femininity, as well as the rigid distinctions between homo- and heterosexuality.

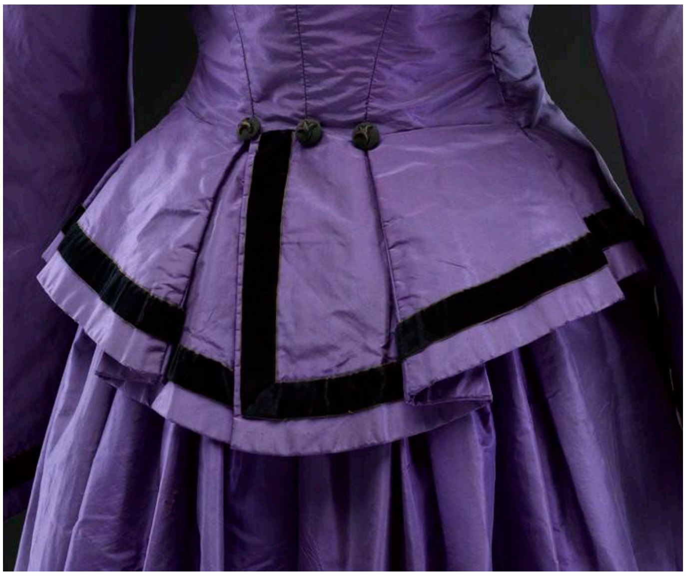


Fig. 1. Silk skirt and blouse dyed with Sir William Henry Perkin's. London: Science Museum Group.

At the heart of a revolution in organic chemistry and the textile industry, violet has accompanied feminist and queer movements, contributing to the emancipation of women, gender and sexual minorities. This positions violet as a colour of modernity, symbolising an ideology oriented toward progress, innovation, and liberation. For the first time, the technical advancements in violet dyeing and painting, its feminist and queer symbolism, and the social and legal progress for women and queer individuals in the 20th century are being woven into a cohesive narrative. Previously, these themes had been studied, but only in isolation from one another. By revisiting the last 150 years of violet's history, this research will examine its deep connection to modernity and its potential role as a colour of the future – perhaps inherently queer. Various studies on violet will be bridged, linking its material, social, cultural, artistic, and spiritual significance. Queer and feminist activist archives will also be analysed, employing a semiotic approach to images and objects, combined with contemporary texts from these sources, to establish connections between subjects that are not always easily reconciled. Positioned at the crossroads of gender studies, cultural studies, the history of social movements, and art history, this research offers a multidisciplinary perspective on the evolution of violet as a symbol of modernity and queer emancipation.

2. The Mauve Decade: Mauveine, Fashion, and Feminism

In 1856, while attempting to synthesise quinine in search of an anti-malarial substance, Perkin realised that by cleaning up the organic waste from his experiments, he was obtaining a violet solution (Cova, Pais, and Seixas de Melo, 2017). The apprentice chemist unwittingly developed the first synthetic dye based on aniline, which he initially called 'aniline purple'. Later known as 'mauveine', this synthetic colour achieved dazzling success, prompting Perkins to borrow money from his father to establish a factory in the year following its discovery. He also introduced the textile industry to his dye, capable of colouring wool and silk in various shades of violet (Fig. 1), which had previously required expensive materials or processes (Beer, 1926). Fashion is linked to modernity – sometimes seen in opposition to it – since, as Nicolas Liucci notes, "the strengthening of modern thought will be concomitant with the exponential development of the fashion industry, which will quickly affect the entire social body" (2008).

Public demand for shades of violet known as 'mauve', 'lilac', or 'heliotrope' surged further under the influence of Eugénie de Montijo, wife of Napoleon III, who found mauve to perfectly match her eyes, and Queen Victoria, who wore a mauve velvet train at her daughter's wedding on 25 January 1858 (Fig. 2), on the advice of Empress Eugénie (Garfield, 2000, pp. 58–59). Violet hues became such a craze in 19th-century European fashion that historians sometimes refer to the final years of the 19th century in Europe and North America as the 'mauve decade' (Delevoy, 1978, pp. 45–68; Beer, 1926). However, the British newspaper *The Punch* negatively described this fashion as "mauve measles", cynically depicting it as a disease whose "ravages are principally among the weaker sex" (Anonymous, 1859).

Fig. 2. Phillip, J. (1860) [extract]. Oil on canvas, 103,2 × 184 cm.

In the 18th century, European women were already the favored customers of fashion retailers; the link between fashion and women continued to strengthen with industrialisation from the late 18th century in the United Kingdom and until the end of the 19th century in other European and North American countries (Chessel, 2012, pp. 69–82). The mechanisation of clothing manufacturing gave rise to ready-to-wear fashion, while the optimisation of printing led to the development of the 'women's press'. Above all, the creation of department stores transformed shopping into the favoured pastime of middle- and upper-class urban women (Rappaport, 1999). Violet was a popular colour at the end of the 19th century, particularly associated with bourgeois women, but often in a negative light, as it was linked to "the vulgarity of cheap fashion, which the aniline revolution had precisely brought about" (Ribeyrol, 2021).

Associated with technological progress, violet also symbolises social progress, as it became the emblem of one of the most famous suffragist organisations: the Women's Social and Political Union (WSPU), founded in 1903 by Emmeline Pankhurst, whose activists earned the nickname 'Suffragettes' [2]. In 1908, Emmeline Pethick-Lawrence proposed the selection of colours to differentiate the WSPU from other organisations, and violet, white, and green were chosen, each representing its symbolic value: "Purple as everyone knows is the royal colour, it stands for the royal blood that flows in the veins of every suffragette, the instinct of freedom and dignity… white stands for purity in private and public life… green is the colour of hope and the emblem of spring" (1908). These three colours quickly became among the most distinctive features of feminist demonstrations, worn by activists in the form of ribbons, scarves, medallions, or clothing, and disseminated via posters, leaflets, and banners (Fig. 3). Across the Atlantic, suffragist Elizabeth Blackwell is said to have found a cryptic message in the choice of these colours, with the initials of the colour names coding different words: 'Violet' for 'Votes', 'Green' for 'Give' and 'White' for 'Women', thus forming 'Give Women Votes', the emblematic slogan of feminists during that period (Florey, 2013, p. 80).

*Fig. 3. WSPU postcard album (*c*. 1911). London: British Library of Political and Economic Science.*

These explanations alone do not fully account for this choice of colours; there was also a practical aspect to consider, ensuring that all suffragettes could easily wear the WSPU colours. Since violet was fashionable – just as green was (Matthews David, 2017) –, most women had at least one item in these colours in their wardrobes, allowing them to assert their political allegiance without making an expensive purchase (Heller, 2000, pp. 172–173). By relying on fashion, which women were thought to have a natural inclination towards, the suffragettes attempted to overcome the negative image of the feminist as "strong-minded," i.e., masculine: "[they] used fashionable dress as a form of propaganda in the belief that 'eccentricity' would make the vote harder to obtain" (Ribeiro, and Blackman, 2015, p. 203). Furthermore, by choosing fashion as a mode of communication and using synthetic colours as an emblem, they personified themselves as avatars of modernity, associated with both novelty and progress enabled by technological innovation.

3. Violet Flowers: Fin-de-Siècle, Decadence, and Homosexualities

These new shades of violet, absent in nature, were especially regarded as abnormal, which contributed to violet's growing popularity within the Decadentism, a fin-de-siècle literary movement (Palacio, 2011) named after the decadence of the Roman Empire (Ward-Perkins, 2005). Although the end of the 19th century had little in common with the turning point of Roman civilisation, the sentiment of decadence was sufficiently pervasive to influence literary creation (Courapied, 2014, p. 48). Historian Michel Winock describes decadence as "above all a vague idea, a pessimistic representation of the world, a nostalgia for what is no longer, a creation of the sullen, alarmist or downright desperate imagination" (2018, p. 4).

This characteristic spleen of the fin-de-siècle coincided with fears arising from societal upheavals accompanying the entry into modernity: the decline of the Church, the social advances for women gaining access to new professions, and the political organisation of the proletariat (*ibidem*). The ambiguous term 'decadence', laden with negative connotations, was used to stigmatise behaviours deemed immoral or unhealthy due to modernity and its progress (Kopp, 2019), including male homosexuality. This notion became the focus of moral, psychiatric, and legal studies, viewed as a symptom of industrialisation that risked depopulating society, leading to a decline of civilisation, as well as a 'vice of luxury' associated with artistic and literary modernity (Tamagne, 2002). Rejecting the virile and moralising values of society, the decadents made the homosexual aesthete and the androgynous figures "a widespread subject, a constitutive element of Decadence" (Palacio, 2011, p. 188).

Decadentism then manifested as a revolt against nature in favour of art or even the artificial, which was crystallised by the numerous references to artificial flowers, mass-produced at the end of the 19th century and often coloured surrealistically with synthetic dyes. Literary researcher Romain Courapied notes that "[t]he decadent aesthete and the ordinary homosexual have a comparable use of flowers, chosen for their surprising colours" (2014, p. 407), particularly green, black, violet, or dark red, which "indicates a predisposition to refinements and desires that are […] the fruit of a perversion of natural conditions" (*ibid*., p. 400). Violet flowers, in particular, were used to suggest depravity in a homosexual context, as in *Messes noires. Lord Lyllian* by Jacques d'Adelswärd-Fersen: in a scene set at the Salle Wagram, a guinguette frequented by homosexual men, young ephebes "had sown violets" on the tables (1905, p. 105). According to Courapied, "the colour violet acts as a paradoxical indicator of a perverse content integrated into pleasing aesthetic forms" (2014, pp. 409–410), referring to the liminal symbolism of violet, which echoes the twilight hues at sunset; it can also evoke disease or putrefied flesh, thus resonating with masculine homosexuality as perversion.

Far from being exclusive to men, violet also references lesbianism through violet flowers. Some theories proposed by lesbian activists suggest that the association of violets with lesbianism is rooted in the Greek poet Sappho, whose texts are rich with allusions to this spring flower and who is believed to have been homosexual due to her declarations of love for other women [3] (Collecott, 1999, p. 91). However, violets are not the only flowers mentioned by Sappho: roses, crocuses, and other flowers adorn her texts, forming a vast garden (Reinach, 1911, p. 732), as is the case in much poetry from this period (Pelletier-Michaud, 2016, pp. 199-201).

In fact, Sappho's association of violets – specifically the violet flower – with lesbianism owes less to her than to Renée Vivien, who translated Sappho's texts in the early 20th century. 'Muse of Violets', Vivien was devoted to this spring flower, which adorned her letter paper and featured in several photographic portraits [4]. The flower also appeared in her writings: Vivien mentions it fifty-four times throughout her works, even using it in the title of one of her books (1910). By extension, Vivien had a passion for the colour violet; she wrote in violet ink, one of her books bore the name 'Violet' (1903), and the colour pervaded her writings until it became "a recurring element of her poetry and an emblem of lesbian love" (Islert, 2021, p. 249). Her obsession with violet – the flower as much as the colour – was undoubtedly linked to her youthful love, Violet Shillito, who died prematurely; "[t]he binomial violet/violette thus refers to a triple reference for Vivien: the name of a colour, the name of a flower, and the proper name of the dead friend" (*ibidem*).

The colour violet can also symbolise lesbianism in 19th-century painting, again in the form of flowers. For example, in Maria Luise Katharina Breslau's oil painting *Contre-jour* (1883; Fig. 4), the Swiss painter depicts herself and her companion in an interior scene, both seated around a low table on which rests a vase filled with flowers that are presumed to be violets. This floral and chromatic link, as well as a symbolic one between the two women, subtly reveals their lesbian relationship to those who can read between the lines in a century when homosexual relations were taboo. Breslau's painting conveys the secrecy required to sustain her romance, achieved through the play of shadows in which the scene is immersed.

Fig. 4. Breslau, M. L. K. (1888) Contre-jour*. Oil on canvas, 113 × 181,5 cm. Bern: Kunstmuseum Bern.*

4. Indigomania: Impressionism, Artificiality, and Degeneration

Deeply influenced by colour theories that proliferated since the publication of Isaac Newton's *Opticks* (1704), the Impressionists played with colour contrasts by juxtaposing complementary hues, using violet to paint shadows that contrasted with the light of yellow suns. Violet became so characteristic of Impressionist painting (Fig. 5) that the British art critic George Moore once mocked Louis Antequin for painting “the street, and everything in it, violet—boots, trousers, hats, coats, lamp-posts, paving-stones, and the tail of the cat disappearing under the porte cochère” (1893, p. 95). The journalist and art critic Albert Wolff suggested in *Le Figaro* that “Monsieur Pissarro should be made to understand that the trees are not violet, that the sky is not fresh butter” (1876); the Impressionists were particularly criticised for choosing colours based on their subjective perception, which no longer reflected nature and therefore seemed artificial, especially since they were now obtained synthetically using aniline (Ribeyrol, 2018).

Taking up *The Punch's* pathologising to the popularisation of mauve among women (Anonymous, 1859), art critics viewed Impressionist painting less from an aesthetic perspective than from a medical and physiological one (Reutersvärd, 1950). French critic Joris-Karl Huysmans thus spoke of an “indigomania [*indigomanie*] that has wreaked such devastation on the ranks of painters” (1883, p. 107). Referring to the work on hysteria by neurologist Jean-Martin Charcot and ophthalmologist Xavier Galezowski (*ibid*., p. 104), Huysmans associated the Impressionists’ ‘manic’ use of violet with neurotic psychological disorders, which could impair the retinas and limit the perception of green in favour of blue and violet (*ibid*., p. 90, 104).

By linking Impressionism to mental disorders, he joined the discourse on the decadence of fin-de-siècle society and the degeneration of art, as described by physician and art critic Max Nordau, who viewed industrial acceleration and modern art as indicative of societal degeneration (1882, pp. 30–31). The considerations given to the Impressionists are therefore similar to those directed at the Decadents, during a time when sexology was emerging and homosexuality became the subject of psychiatric study (Courapied, 2014). The difference is that while the Decadents took a clear stance on this theme, the Impressionists never addressed it directly or did so only subtly.

*Fig. 5. Sargent, J. S. (*c*. 1885-1886)* Carnation, Lily, Lily, Rose*. Oil on canvas, 174 × 153,7 cm. London: Tate Britain.*

5. Ultraviolets: Queer Communities, Activism, and Social Change

The late 19th century saw the rise of ‘modern homosexuality’, with lesbians and homosexual men becoming increasingly visible – sometimes perhaps unwillingly – due to growing medical interest and the emergence of a ‘homosexual world’ in major cities, notably Paris, London, and New York, which remained an underworld (Latimer, 2005; Revenin, 2006). Violet then emerged as a code to signify homosexuality and to identify fellow homosexuals, a sign not necessarily recognised by heterosexuals.

After the First World War, the associations between violet and homosexuality were perpetuated and strengthened. In Germany and Austria, "the colour purple became the code of the [lesbian and male homosexual] subculture" in the 1920s (Hacker, 2015), while in English-speaking countries, the slang expression "a streak of lavender" designated an effeminate man (Pollock, 1935, p. 115). The homosexual connotation of violet gained popularity in the 1930s (Delessert, 2012), and in the 1950s, the homophobic US senator Everett Dirksen used the expression "lavender lads" to refer to homosexual men (Johnson, 2004, p. 18). On 31 October 1969, violet was once again associated with homosexuality when journalists from the *San Francisco Examiner* threw violet ink at queer activists protesting a homophobic article (Bideaux, 2023a, p. 425).

Fig. 6. Purple rhinoceros from the 'Lavender Line' project, made in papier-mache for the Boston Pride March (1974).

A few years later, violet was associated with queer identity through the use of a purple rhinoceros in the advertising campaign dubbed 'Lavender Line' by Gay Media Action-Advertising. Aiming to raise the profile of gay and lesbian individuals through posters in the Boston metro system, the campaign used a violet rhinoceros as an allegory for homosexuality (Fig. 6). The animal was chosen for its inoffensiveness but also for its potential to be a frightening beast when provoked, while the colour symbolically combined the feminine and the masculine, as purple is a mixture of pink and blue [5] (Gray, 2019).

Fig. 7. Calvès, M. (1979) March for free abortion and contraception, Paris, 6 October 1979.

Meanwhile, violet remained a feminist emblem in Europe and North America and continues to be today. In creating a link with the Suffragettes' emblem, feminists of the 1960s and 1970s imbued it with new meaning: as violet is a mixture of blue and pink – the traditional colours of layettes –, it signified the desire to dismantle gender stereotypes and to achieve gender equality (*ibid*., p. 304; Fig. 7). Choosing violet also differentiated them from other political movements with established colour emblems (red for communists, black for anarchists). Divisions within feminist movements were even symbolised by different shades of violet: the lesbians of the National Organization for Women (NOW) were labelled a 'lavender menace' by president Betty Friedan, who feared that their masculine appearance and animosity toward men would undermine the movement (Brownmiller, 1999, p. 82). In contrast, black feminist activist Alice Walker associated lavender with a 'white feminism' that rejected the integration of gender and race issues, while she linked purple to an intersectional feminism promoted by black women, which she termed 'womanism' [6] (1983, pp. XI–XII).

By the end of the 1990s, the symbolism of violet had become more inclusive, incorporating new meanings that extended beyond homosexuality. It began to encompass bisexuality, with the bisexual pride flag featuring three stripes: a pink stripe signifying homosexuality, a blue stripe representing heterosexuality, and a violet stripe – a mixture of the first two – symbolising bisexuality (Fig. 7; Page, 1998). In the 2000s, violet also became emblematic of transgender struggles and identities, chosen again for its representation of both 'pink for girls' and 'blue for boys' in one of the transgender pride flags (Fig. 8; Pellinen, 2002). In the following decade, it appeared alongside yellow, white, and black in the non-binary pride flag (Fig. 9), representing individuals who identify between masculine and feminine gender identities (Fig. 10; Rowan, 2014). Violet thus mutates into ultraviolet, a light with a wavelength outside the visible spectrum, becoming a metaphor for the search for a “beyond gender” that challenges both feminine/masculine and homo-/heterosexual binaries.

Fig. 8. Page, M. (1998) Bi Pride Flag.

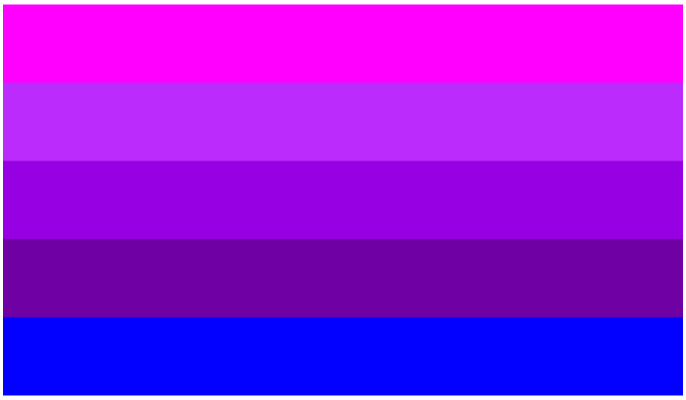


Fig. 9: Pellinen, J. (2002) Transgender Pride Flag.

Fig. 10. Rowan, K. (2014) Non-binary Pride Flag.

6. Conclusions: Twilight Visions of Queer Futures

It is clear that violet symbolically represents technological progress, artistic innovation, and the ever-evolving novelty of fashion. Conversely, it also aligns with emerging conceptions of homosexuality, the struggles for gender and sexual minority rights, and the possibilities for women and queer individuals to live freely. Since the late 19th century, it has been seen as the “subversive colour of modernity” as much as that of queer utopian perspectives. Even today, violet is used to evoke better futures, where progress is combined with individual development and freedom. It is thus the colour most associated with cyberspaces – now referred to as metaverses – perceived as a liminal colour that fuses the digital world – symbolised by the blue of the internet – with the physical world – symbolised by the red blood of our flesh (Bideaux, 2023b). Imagining the metaverse in violet also entails viewing digital worlds as queer spaces, where anonymity allows individuals to transcend questions of gender or sexuality and fully experience their individuality (Lau, 2014).

As the last light in the visible spectrum to be perceived before darkness, violet is also the colour of twilight – the liminal colour between day and night, between the visible and the invisible. As we have seen, it symbolically plays with the limits of femininity and masculinity, as well as homo- and heterosexuality. Associated with modernity, violet signifies the transition between the present and the future, yet it also embodies a convergence between queer utopia and straight dystopia. Indeed, modernity has not always been synonymous with queerness, as the discovery of mauveine served to stigmatise bourgeois women (Ribeyrol, 2021) and advances in psychiatric medicine facilitated the oppression and repression of homosexuals (Courapied, 2014). At the same time, certain feminist achievements may have overlooked both racialised women (Walker, 1983) and transgender women (Worthen, 2022). Additionally, gays and lesbians often lack solidarity with bisexual and transgender individuals, and in some cases even discriminate against them (Weiss, 2011).

While modernity may not be fully realised without the emancipation of all, there is no guarantee that the future will be queer, at least within the Western symbolic framework. However, if envisioned correctly, violet – and even more so ultraviolet – will likely continue to serve as enduring symbols of queer modernity.

7. Conflict of interest declaration

It is confirmed that there are no conflicts of interest related to this publication, and no substantial financial support has been provided that could have influenced the results or conclusions of this work.

8. Funding source declaration

This article was partially funded by a post-doctoral grant from the University of Paris 8 Vincennes–Saint-Denis (France).

9. Acknowledgment

I would like to express my gratitude to Olivier Thuillier and Trystan Pierrart for their proofreading and assistance with the translation, and to my former student, Ariane Tassin, for her insightful contributions to the study of twentieth-century lesbian portraiture. I also extend my thanks to Chaim Ebene Narang for his meticulous final revisions.

10. Short biography of the author

Kévin Bideaux (they/he/she/it) are an artist-researcher specialising in arts and gender studies, with a focus on the intersection of colours and gender representations. In 2022, they were awarded the Institut du Genre prize for their doctoral thesis, which explores the cultural and symbolic history of pink in relation to gender and sexualities. Currently, they are investigating the colour purple within the context of gender, sexualities, and feminist and queer movements.

Notes

[1] While ‘purple’ and ‘violet’ are colour terms that can be used interchangeably in English (Matschi, 2005), ‘violet’ is preferred here, as it is more commonly associated with the part of the visible spectrum that has the shortest wavelengths, whereas “purple” tends to refer to various combinations of red, blue, and violet. This connection to light, particularly ultraviolet rays – which will be discussed at the end of the article – is considered more aligned with the concept of modernity discussed in this context, while ‘purple’ relates more to the ancient dye obtained from murex.

[2] From the outset, the Women’s Social and Political Union (WSPU) positioned itself as distinct from other suffragist movements, which it viewed as too moderate. The WSPU preferred more radical forms of action to achieve results. In a press article in the *Daily Mail* in 1906, the journalist Charles E. Hands referred to them as ‘suffragettes’, a term used pejoratively to mock them, the suffix ‘-ette’ conveying a diminutive sense. They decided to reclaim the term, and ‘suffragette’ came to describe all committed women who resorted to violent methods.

[3] In particular, in her *Ode to Aphrodite*, the only complete poem by Sappho that has been found, she addresses a prayer to the goddess of beauty, asking her to ensure that the woman she loves returns her affection (1903, pp. 3–9).

[4] The association between violet and lesbianism is relatively recent. Around 1833, the Marquise Henriette de Mannoury d'Ectot published *Le Roman de Violette* (*c.* 1833), the first known erotic story written by a woman, notable particularly for its Sapphic scenes. The name ‘Violette’ refers to the protagonist, a young linen maid encouraged by her lover to yield to the advances of Countess Odette de Mainfroy.

[5] Initially planned for the Boston Pride March, the launch of the campaign was delayed due to an increase in advertising costs announced two months after the project began. However, 100 posters were displayed in the Boston underground at the end of 1974. Despite a brief reappearance at the Boston Pride March in 1976, the purple rhinoceros never achieved the popularity it had hoped for.

[6] ‘Purple’ and ‘lavender’ are used symbolically here in reference to their positions within the chromatic field of violet: in English, ‘purple’ designates a broad spectrum of shades, with ‘lavender’ being one of those nuances. By analogy, the white feminism critiqued by Walker is only part of womanism, which aims to be more inclusive.

Licensing terms

References

Adelswärd-Fersen (d'), J. (1905) *Messes noires. Lord Lyllian*. Reprint, Montpellier, GayKitschCamp, 2011.

Anonymous (1859) ‘Mauve Measles’, *The Punch, or the London charivari*, 20 August, p. 81.

Beer, T. (1926) *The Mauve Decade: American life at the end of the Nineteenth Century*. Reprint, Whitefish: Kessinger, 2004.

Bideaux, K. (2023a) *Rose. Une couleur aux prises avec le genre*. Paris: Éditions Amsterdam.

Bideaux, K. (2023b) *Investigation into the colours associated with the Internet, the virtual and the metaverse*. Unpublished.

Brownmiller, S. (1999) *In Our Time: Memoir of a Revolution*. New York: Delta.

Chessel, M.-E. (2012) *Histoire de la consommation*. Paris: La Découverte.

Collecott, D. (1999) *H.D. and sapphic modernism 1910-1950.* Cambridge: Cambridge University Press.

Cova, T. F. G. G., Pais, A. A. C. C., and Seixas de Melo, J. S (2017) ‘Reconstructing the historical synthesis of mauveine from Perkin and Caro: Procedure and details’, *Scientific Reports*, 7, art. 6806. doi: 10.1038/s41598-017-07239-z.

Courapied, R. (2014) *Le Traitement esthétique de l'homosexualité dans les œuvres décadentes face au système médical et légal : accords et désaccords sur une éthique de la sexualité*. PhD in French literature. University Rennes 2. Available at: https://tel.archives-ouvertes.fr/tel-01127446 (Accessed: 17 May 2024).

Delessert, T. (2012) ‘Le “Milieu” homosexuel suisse durant la Seconde Guerre mondiale’, *Cahiers d'histoire. Revue d'histoire critique*, 119. doi: 10.4000/chrhc.2731.

Delevoy, R. (1978) *Le Symbolisme*. 2nd edn. Paris: Skira, 1982.

Florey, K. (2013) *Women's Suffrage memorabilia: An illustrated historical study*. Jefferson: McFarland and Co. Inc.

Garfield, S. (2000) *Mauve. How one man invented a colour that changed the World*. Londres: Faber and Faber.

Gray, A. (2019) ‘How A Lavender Rhino Became A Symbol Of Gay Resistance In '70s Boston’, *wbur*, 3 June. Available at: https://wbur.fm/3U5n6aK (Accessed: 17 May 2024).

Hacker, H. (2015) ‘Farbencodes/Codefarben : Lila, violet’, *Frauen* und Freund_innen. ‘Lesarten weiblicher Homosexualität’ Österreich, 1870-1938*. Vienne: Zaglossus, pp. 306–308.

Huysmans, J.-K. (1883) ‘L’Exposition des indépendants en 1880’, *L'Art moderne*. Reprint, Paris: P.-V. Stock, 1902, pp. 97–140. Available at: https://gallica.bnf.fr/ark:/12148/bpt6k5438935k (Accessed: 17 May 2024).

Johnson, D. K. (2004) *The Lavender scare: The Cold War persecution of gays and lesbians in the federal government*. Chicago: University of Chicago Press.

Heller, E. (2000) *Psychologie de la couleur. Effets et symboliques*. Translated by L. Richard. Paris: Pyramyd, 2009.

Kopp, R. (2019) ‘Décadence et modernité’, *Revue des deux mondes*, February-March, pp. 51–55.

Islert, C. (2021) *Renée Vivien. Une poétique sous influence*. PhD in modern literature. University Sorbonne Nouvelle. Available at: https://theses.hal.science/tel-03883263 (Accessed: 17 May 2024).

Latimer, T. T. (2005) *Women Together/Women Apart: Portraits of Lesbian Paris*. New Brunswick/New Jersey/London: Rutgers University Press.

Lau, K. W. (2014) ‘The gender differences in metaverse: a study of university art and design students’, *Open journal of art and communication*, 1 (1), pp. 14–19.

Liucci, N. (2008) ‘Tensions entre mode et modernité’, *Institut français de la mode*. Available at: https://bit.ly/Liucci2008 (Accessed: 17 May 2024).

Mannoury d'Ectot (de), H. (c. 1883). *Le Roman de Violette*. Reprint, Paris: Serpent à Plume, 2002.

Matschi, M. (2005) 'Color terms in English: Onomasiological and Semasiological aspects’, *Onomasiology Online*, 5, pp. 56–139. Available at: https://www1.ku.de/SLF/EngluVglSW/matschi1041.pdf (Accessed: 17 May 2024).

Matthews David, A. (2017) ‘Pigments empoisonnés. Les Verts arsenicaux’, *La Peaulogie*, 1. Available at: http://lapeaulogie.fr/pigments-empoisonnes-les-verts-arsenicaux (Accessed: 17 May 2024).

Moore, G. (1893) *Modern Painting*. London: Walter Scott.

Nordau, M. (1892) *Dégénérescence*, t. 1: *Fin de siècle. Le Mysticisme*. Translated by A. Dietrich. Paris: Félix Alcan, 1894.

Newton, I. (1704) *Opticks or, a Treatise of the reflexions, refractions, inflexions and colours of light . Also two treatises of the species and magnitude of curvilinear figures*. London: Sam. Smith. and Benj. Walford. Available at: http://catalogue.bnf.fr/ark:/12148/cb36118888z (Accessed: 17 May 2024).

Palacio (de), J (2011) *La Décadence : le mot et la chose*. Paris, Les Belles Lettres.

Page, M. (1998) ‘History of the bi pride flag’, Biflag. Available at: https://bit.ly/Page1998 (Accessed: 17 May 2024).

Pelletier-Michaud, L. (2016) *Évolution du sens des termes de couleur et de leur traitement poétique. L’Élégie romaine et ses modèles grecs*. PhD in ancient studies. Laval University. Available at: https://bit.ly/PelletierMichaud2016 (Accessed: 17 May 2024).

Pellinen, J. (2002) ‘Transgender Flag info’, *transflag.org*. Available at: https://bit.ly/Pellinentransflag (Accessed: 17 May 2024).

Pethick-Lawrence E. (1908) *Votes for Women*. Cited by D. Fairhall (2006) Common Ground. Londres/New York: Tauris, p. 31.

Pollock, A. J. (1935) *The Underworld speaks: An insight to vice-crime-corruption*. San Francisco: Prevent Crime Bureau. Available at: https://catalog.hathitrust.org/Record/006151236 (Accessed: 17 May 2024).

Rappaport, E. (1999) *Shopping for Pleasure: Women in the Making of London’s West End*. Princeton: Princeton University Press.

Reinach, T. (1911) ‘Pour mieux connaître Sappho’, Comptes rendus des séances de l'Académie des Inscriptions et Belles-Lettres, 55e année, 9, pp. 718–734.

Reutersvärd, O. (1950) ‘The “Violettomania” of the Impressionists’, *Journal of Aesthetics and Art Criticism*, 9 (2), pp. 106–110. doi: 10.2307/426328.

Revenin, R. (2006) ‘L'émergence d'un monde homosexuel moderne dans le Paris de la Belle Époque’, *Revue d’histoire moderne & contemporaine*, 53 (4), pp. 74–86. doi: 10.3917/rhmc.534.0074.

Ribeiro, A., and Blackman, C. (2015) *A portrait of fashion: six centuries of dress at the National Portrait Gallery*. London: National Portrait Gallery.

Ribeyrol, C. (2018) ‘John Singer Sargent and the fin de siècle Culture of Mauve’, *Visual Culture in Britain*, 19(1), pp. 6–26. doi: 10.1080/14714787.2018.1447992.

Ribeyrol, C. (2021) ‘Verdeurs: Oscar Wilde, Dorian Gray, and the Colors of Decadence’, *Victorian Literature and Culture*, 49 (4), pp. 753–775. doi: 10.1017/S1060150320000261.

Rowan, K. (2014) ‘[no title]’, *Tumblr*, 24 february. Available at: https://bit.ly/nonbinaryflag (Accessed: 17 May 2024).

Sappho (1903) *Sapho*. Vivien, R. (ed.). Paris: Alphonse Lemerre.

Tamagne, F. (2002) ‘Figures de l’étrange et de l’étranger : la peur de l’homosexuel(le) dans l’imaginaire occidental (1880-1945)’, *Annales de Bretagne et des Pays de l’Ouest*, 109 (2), pp. 129–142. doi: 10.4000/abpo.1618.

Vivien, R. (1903) *Du vert au violet*. Paris: Alphonse Lemerre.

Vivien, R. (1910) *Dans un coin de violettes*. Paris: E. Sansot et Cie.

Walker, A. (1983) *In Search of Our Mothers’ Gardens*. New York: Harvest Books.

Ward-Perkins, B. (2005) *The Fall of Rome and the end of civilization*. Oxford: Oxford University Press.

Weiss, J. (2011) ‘Reflective Paper: GL Versus BT: The Archaeology of Biphobia and Transphobia Within the U.S. Gay and Lesbian Community’, *Journal of Bisexuality*, 11 (4), pp. 498–502. doi: 10.1080/15299716.2011.620848.

Wolff, A. (1876) ‘Le Calendrier Parisisen’, *Le Figaro*, 3 April, p. 1. Available at: https://gallica.bnf.fr/ark:/12148/bpt6k275925t.texteImage (Accessed: 17 May 2024).

Worthen, M. G. F. (2022) ‘This is my TERF! Lesbian Feminists and the Stigmatization of Trans Women’, *Sexuality & Culture*, 26, pp. 1782–1803. doi: 10.1007/s12119-022-09970-w.

A playful approach for early screening of color blindness in Italian primary schools

Carlo Alberto Iocco[1], Alice Plutino[1], Ambra Cattaneo[1], Luca Armellin[1], Matteo Sassi[2], Liliana Silva[3], Alessandro Rizzi[1,2]

[1]*MIPS Lab, Department of Computer Science, University of Milan*

[2]*SAZ (Spiele Autoren Zunft eV) Italy*

[3] *Department of Education and Human Sciences, University of Modena and Reggio Emilia*

Corresponding author: Carlo Alberto Iocco (carlo.iocco@unimi.it)

ABSTRACT

The term color blindness in humans indicates a condition of hypo-functioning of a class of cones, a specific type of cells in the retina, which leads the subject to confuse colors or perceive some tones in a limited way. Approximately 8% of European men and 1% of European women are affected by color blindness, and in Italy the number of color-blind individuals is around 2.2-2.5 million. Color blindness is a condition related to genetic transmission and is therefore present from birth, but in Italy it is often diagnosed after adolescence.

The work described in this paper is part of a larger research project called Game4CED regarding color blindness and board games. This paper tests the possibility of diagnosing color blindness in childhood, in a playful way, using board games, to provide teaching staff, tutors and educators with support and techniques for testing in classrooms. This approach is not intended to replace a medical examination, which is necessary if a potentially color-blind child is identified but aims to propose a preliminary screening avoiding the stress of a medical analysis.

The experiment was organized at the "Dante Alighieri" Primary School of the Giovanni XXIII Comprehensive Institute of Arona (NO) and involved a sample of approximately 120 kids under 10 years, from classes from the first to the fourth grade. For the experiment some customized versions of famous board games have been prepared, in which color sensitivity is significant. The games used (SpeedColor, Dobble, Nimble and Fantascatti) have been specifically modified in such a way as to reduce the logical associations between colors and shapes, in order to work as much as possible on visual perception with the less possible cognitive processing. In addition to board games, the subjects who presented greater difficulties have been further screened with the online game qolour (http://qolour.it) to exclude any false positives.

The proposed method proved useful for involving the analyzed subjects. The success in identifying some cases attests that the approach used by the study group was effective in the early diagnosis of the disorder.

KEYWORDS color, color blindness, screening

RECEIVED 19/09/2024; **REVISED** 27/09/2024; **ACCEPTED** 07/11/2024;

1. Introduction

Color blindness is a genetic condition which, in a percentage of individuals, causes the hypofunction of a class of cones cells in the human retina which makes it difficult to perceive and distinguish some colors. About 8% of European men and 1% of European women are affected. In Italy, the number of color-blind individuals is around 2.2-2.5 million (Wright and Martin 1946), (Birch 2012), but the diagnosis is often made only after adolescence. Currently the most used methods for testing color blindness are the Ishihara Test and the Farnsworth-Munsell Test (Birch and McKeever, "Survey of the accuracy of new pseudoisochromatic plates" 1993), (Cole 2007), which can be associated to more accurate clinical tests such as the Nagel anomaloscope or the CAD test.

Color blindness diagnostic tests are carried out mainly for the purpose of issuing authorizations to drive vehicles (e.g. driving license) and for carrying out specific tasks. For this reason, many color blindness diagnoses are made in adulthood, especially in cases of mild color blindness, or in subjects for whom color blindness was masked by other types of dysfunctions.

Furthermore, diagnostic tests for color blindness require trained and specialized personnel, as well as high levels of attention from patients. This makes many tests difficult for children or individuals with attention deficits (Armellin, Plutino, and Rizzi 2022).

Early diagnosis of color blindness is essential for adequate management of any problems associated with this condition, especially at school. Untrained teaching staff, and lack of knowledge of this phenomenon, could cause stress, exclusion or discrimination of color-blind children, as well as slow down their learning pace.

In this context, proper teacher training, associated with some specific board games as tools, could be a first solution. Using board games as an early diagnostic tool has numerous benefits. Games are a playful and engaging method that allows you to test children's ability to recognize colors in a fun way, without creating stress and without affecting their motivation. Furthermore, games are an easily accessible and low-cost method, suitable for varying age groups and contexts, such as school.

2. Game4Ced

The Game 4 CED project has been considered valuable by the Ministry of University and Research, which has decided to support and provide the funds necessary for its completion.

Game4Ced has four main objectives:

1. Development of a board game as an educational tool for the early detection of color blindness increasing people's awareness of color blindness
2. Analyze and improve accessibility standards for color blind people in the world of board games
3. Provide teachers, educators and parents of school-age children with tools and knowledge useful for using the board game as an accessible aggregation tool

The project is structured into various sub-goals. The first is the definition of a tool capable of analyzing and evaluating the color-blind accessibility of modern board games. During this phase we will explore the state of the art of accessibility policies and, above all, their actual functioning. To do this, it will be important to keep track of the feedback from color-blind players against the complexities encountered while playing various board games. There are mainly two objectives. The first is to correctly frame the problem and understand the level of attention and awareness of the industry today. The second is to comply with these standards and apply them correctly when designing our games.

Then the main goal will be the design, development and playtesting of ColorFit, the first board game we have created for this goal, and a set of other board games and instruments that can be used to execute an initial screening of players.

Then the main goal will be the design, development and playtesting of a set of board games that can be used to execute an initial screening of players.

The games will then be brought to real contexts, mainly schools and board game fairs, where they will also be a tool for disseminating problems related to color blindness. Educators and teachers in school will therefore be of fundamental importance given that they will be trained on the use of games in order to be able to organize game sessions that have the dual purpose of transmitting the gaming culture in schools and creating a relaxed and favorable environment for carrying out of initial screening of subjects suffering from color blindness.

The aim of the project is to develop an educational toolkit composed of videos, booklets and educational materials that can guide educators and children in creating a more accessible environment. The material will have the aim of training staff on issues relating to color blindness and allowing the autonomous use of ColorFit and other playful tools to carry out an initial screening of people affected by color blindness in a school environment.

3. The test in the school

A first test of ColorFit and other selected modified versions of different board games was conducted at the "Dante Alighieri" Primary School of the Giovanni XXIII Comprehensive Institute of Arona (NO). Two third-year classes, a second-year class and a first-year class participated in the experiment, involving a sample of approximately 120 children under 10 years of age divided approximately equally between males and females.

The experimentation took place in four phases: (a) presentation of the project and brief explanation of the games; (b) division of the class into four groups; (c) conduct of the games; (d) conclusion and greetings. It is important to specify that the project was presented to the children as if the activity had exclusively recreational purposes without mentioning the focus on the search for players who could have altered color perception. On average the four groups had about 20 minutes to play multiple sessions of each game, at the end of which they changed games. Each group of children was led by a researcher, who remained fixed in the group (see Fig. 1). Each researcher had tables available to take note of variables such as the time it took to finish a game, the scores made by the various children and some notes. All data were collected anonymously.

Fig. 1 - The research group of the University of Milan carrying out the tests together with the students of the Comprehensive Institute Giovanni XXIII of Arona (NO).

The board games used were ColorFit, the first game we designed entirely, and modified versions of pre-existing games such as Dobble, Speed Color or Nimble. The goal of the alterations made to these games is to simplify any gameplay task that is not strictly related to color recognition. Furthermore, we have decided to modify the original colors in order to analyze the widest possible color distribution. We used the same 6 color palette for all the games presented here in the sRGB color space:

Colors/sRGB	R	G	B
Yellow	253	241	0
Orange	255	127	38
Red	237	27	36
Green	33	175	80
Blue	0	162	231
Purple	163	73	163

Table 1 - A table showing the values in the sRGB space of the colors used in the modified versions of the board games used during the activity

It is important to underline that some variables regarding the production and visual rendering of the chosen colors are not completely under our control. Depending on the characteristics of the printer used to produce the prototypes, these could show some variations. Other visual variations certainly come from the fact that a school is not a place where it is possible to completely control the light sources and the arrangement of the tables where the tests are set up. In addition to the problems described, it should also be noted that the materials of some games have been plasticized in order to be more resistant and durable. This also leads to possible chromatic appearance due to the reflections that light can generate.

However, we consider the presence of these visual alterations to have a very marginal impact on the experimentation since this is not intended to be a medical test but only an activity with screening purposes.

ColorFit:

ColorFit is an abstract tile placement game for two players. Each player starts with 8 tiles of different colors, each with one of the colors represented on the game board. During their turn, players can place a tile on a free node on the game board as long as this has the same color as the node and that the node is connected to at least one node already occupied by a tile. The first player to play all his tiles wins. ColorFit requires players to develop a strategy with the aim of forcing the opponent into an area of the graph where he cannot place any tiles. At the same time, however, the game tests players' ability to recognize colors. ColorFit is also extremely customizable and can be used in various contexts. In fact, we have created game boards and tiles with various color palettes capable of testing various types of color vision deficiencies.

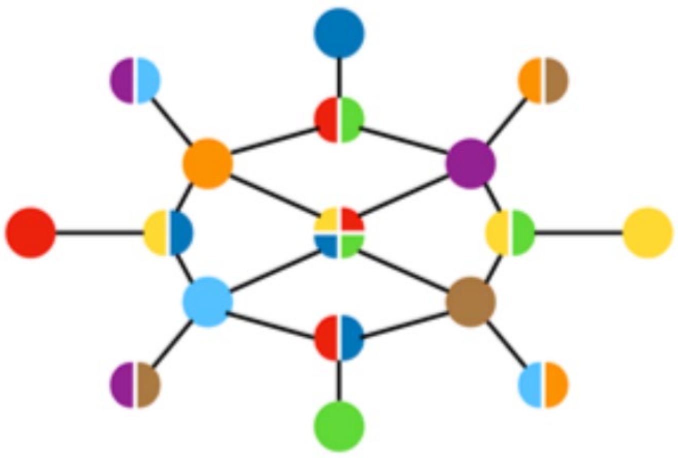


Fig. 2 - A game board from ColorFit

Dobble:

Dobble is a game made up of 55 cards (usually round shape), each of which contains 8 drawn symbols; In the game, there is always only one symbol in common between two cards. The aim of the game is to be as quick as possible to identify the common symbol, declare it out loud, and collect as many cards as possible. The images used were created using the PC application Krita, which allows you to use color selection and color correction gradients tools to uniform the colors of the image. For the game have been used simple images like triangles, squares, circles and hearts, etc each with a uniform color. Dobble has been alterated to simplify the various shapes on the cards with the aim of making the task of recognizing them less complex. Each shape has a black border and is filled with a single color.

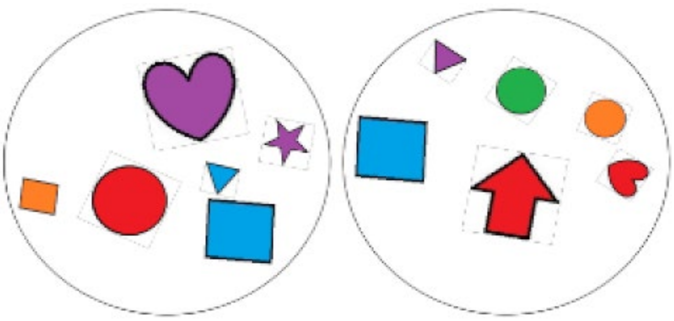


Fig. 3 - Two cards from the modified version of Dobble

Fantascatti:

Fantascatti is a game made up of a deck of cards and five colored tokens representing objects and characters all different in shape and color.

At the beginning of each round the five pawns are placed in the center of the table. Then, the top card of the deck is turned over and positioned in such a way as to be clearly visible to all players. Depending on the colors and images present on the drawn card the players must grab the pawn perfectly represented in the image (therefore with the same shape and the same color) or, if it is not present, grab the piece of the only color does not present in the image. The first player to grab the correct piece shown on the card previously drawn wins. The players then reposition the pawns to the center of the table and place the next card in the center of the table. We used the standard version of Fantascatti.

SpeedColor:

SpeedColor is a color memory game based on vision, the analysis of the colors of an image and their position. Each player has 6 markers and/or colored pencils namely red, orange, yellow, green, blue and purple. For this game, we allowed the children to choose their own pencils, with the restriction that they were like the colors we indicated. In this specific game, it is not necessary to check specific colors; what matters is that they are used to color in the correct area of the previously shown drawing. The colored cards we provide, on the other hand, follow the same color scheme as we displayed in the table. Each card in a SpeedColor deck has a black and white front image and on the back of the card the same image colored with 5 different colors selected from the colors of markers. At the beginning of each round each player takes a card from the deck and places it in front of him on the colored side. Each player then memorizes the colors and their position in the image, after which he turns the card over on the black and white side and, without turning the paper over, he must color it exactly like the image on the colored side. Once they have finished coloring, the players draw the next card of the deck and repeat the process. Points are earned based on how many parts of the card have been colored correctly and, at the end of a game, the player who has scored more points wins.

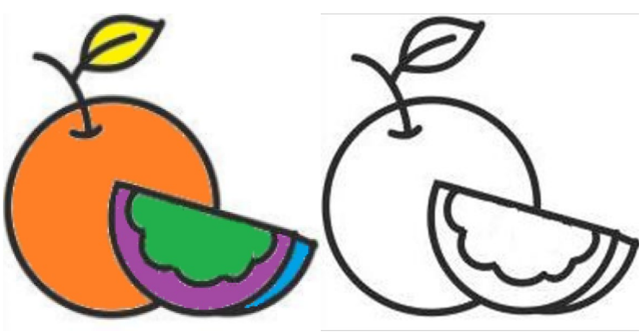


Fig. 4 - Two cards from SpeedColor

Nimble:

Nimble is a board game where motion speed and vision processing speed are put to the test. The game itself is very simple: each player starts with their own deck of cards in hand, recognizable from the symbols on the back. On the front side of the cards there is a monochrome circle and background distinctly colored. At the start of a game of Nimble, you place a card of an extra deck in the center of the table. The players at this point can place a card from their pile above the extracted card, only if the color of the edge of their own card matches the color of the circle in the center of the card in play. The game ends when the time is finished, or a player runs out of cards. At the end of a game, the player with the fewest cards in his hand wins. Nimble has been modified by removing the pattern present on the original cards and simplifying the colors to make the game objects simpler and to focus the players on the colors.

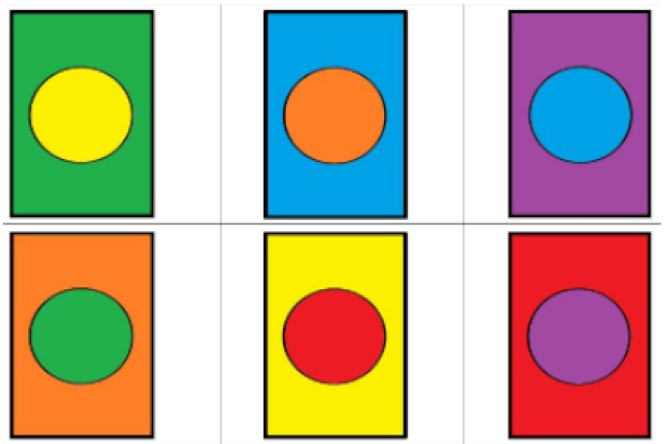


Fig. 5 - Six cards from the modified version of Nimble

In addition to board games, during the gaming session, the students who presented the most difficulties were asked to play the online game qolour. In this case children were chosen arbitrarily, or at their request. Since the qolour game can be solved individually, it was not possible to test all the subjects involved in the test.

Qolour:

Qolour is an online game available for both computer and telephone which consists of showing to the player a monochromatic geometric figure and around it six other similar figures which differ only in shades of a color. The objective of the game is to select the outer figure that has the same color as the central figure.

The game ends when time runs out or too many errors are made and, at the end of a game, statistical data related to the type of errors made and whether a possible visual anomaly is present is reported (Armellin, Plutino and Rizzi 2022). The reliability of the qolour game for a preliminary screening of color blindness has been tested in several studies, and in this experimental context, it was used as a method to have a first distinction between children who had difficulties in the game due to possible color blindness, from children who presented difficulties due to other problems.

4.Results

In general we can confirm that the project carried out at the Dante Alighieri Primary School was successful thanks to the collaboration with the coordinators and teachers of the school. The welcome that the teachers gave to the researchers allowed for excellent integration of the latter into the classroom, allowing from the first moment to create a relaxed and playful environment for the children, making the observation conditions ideal. Furthermore, the students immediately proved to be very enthusiastic about being able to participate in an experiment that had a playful component.

Overall, field observations and subsequent data collection did not highlight significant problems and the possible presence of students with color blindness was found in two out of four classes. Clearly, we would like to point out that this data collection and these results are not comparable to in-depth medical examinations, and are intended to provide parents, teachers and educators only with a preliminary idea of the presence of color blindness. Consequently, for positive cases of visual impairment we recommend examining the results with specialized eye examinations.

In the first third grade, a case of possible deficit in color vision was observed. In all the games, a student showed clear difficulties in identifying colors from the very first moments. In any case, the student is well integrated into the class and supported by classmates and teachers.

In the second grade, some cases of possible vision impairment were observed. Two female students showed difficulties in color discrimination. Given the rarity of color blindness in females, a more in-depth analysis was recommended to the family. Finally, a male student made several errors in color discrimination and became very nervous while playing the games. Also in this case, more in-depth screening was recommended.

In the third grade, no cases of color vision deficits were found. Difficulty was noted in playing the games by a student, who sometimes struggled to maintain attention and carry out the assigned tasks, but the analysis carried out with qolour together with an evaluation carried out by the teachers, revealed that the student has not color vision problems, and his difficulties are only behavioral and/or linguistic.

All students carried out the required activities as expected, showing only some normal competitive behaviors. The use of board games promoted interaction between classmates.

Several insights and ideas emerged from the experiments conducted in primary schools to enhance awareness about color blindness. Specifically, there will be a dissemination of the games used, as well as the qolour gaming app (https://qolour.it/), which is beneficial for conducting initial screenings for color blindness. Additionally, training courses will be developed for teachers and educators on this topic. The analysis, particularly if conducted by teachers and educators trained in behavioral disorders, could be beneficial in the future for making initial observations. Therefore, we recommend that teachers introduce or incorporate board games and similar activities to observe students when they are more playful and spontaneous.

5. Conclusions

In conclusion, the early diagnosis of color blindness through board games represents a useful step forward for the prevention of any discomfort associated with the condition. Thanks to the use of personalized games adapted for each specific pathology, individuals with difficulties in color perception can be identified quickly and effectively.

The research project of which this experiment is part is therefore interesting from several points of view. The possibility of designing and disseminating free and print-and-play board games with the same characteristics as those already described in this document would allow individual schools to carry out tests and game sessions independently and more regularly. Consequently, teacher's knowledge regarding visual elements in everyday teaching that can be problematic for color-blind players would also increase. Furthermore, it is presumable that through the expansion of this project the understanding of color blindness and its functioning will be clearer and more widespread in the school. This can be an extremely important factor in providing support and tools to people affected by this condition.

We want to conclude by recalling that the board games approach in no way replaces a medical examination but represents a valid support for the early diagnosis of color vision deficiencies.

6. Conflict of interest declaration

The authors declare no conflict of interest.

7. Funding source declaration

This work has been supported by the project Game4Ced, Gamification for color blindness early detection, granted by the Italian Ministry of University and Research (MUR PRIN PNRR, CUP Master G53D2300721-0001).

Thanks to Peter Jürgensen, the author of Nimble, for the fruitful discussion regarding the use of his game during the experiment described in this document.

8. Short biography of the author(s)

Carlo Alberto Iocco - researcher at University of Milan (Italy) specialized in video game design, board game design and visual accessibility issues of these medium.

Alice Plutino - Alice Plutino (Phd, Università degli Studi di Milano, 2021) is MSCA Postdoctoral Fellow at the Faculty of Media Studies of the University of Amsterdam. Her research interests are Color Science, Colorimetry, Image Enhancement, Image Digitization, and Archiving, with a particular interest in Cultural Heritage applications.

Ambra Cattaneo - Ambra Cattaneo has obtained a Master's degree in Cultural Heritage Conservation Science at the University of Milano (Italy). She has done a master's degree thesis on characterizing color photographic films' gamut. She also led a project on the preliminary identification of color photographic processes by examining photographic prints

Luca Armellin - Luca Armellin is currently a master's degree student in Computer Science at the University of Milano (Italy). His research interests mainly focus on Vision Impairments with particular attention to Color Vision Deficiencies Colorimetry and Color Science, Lighting, Image Processing and Computer Vision.

Matteo Sassi - Matteo Sassi received his Ph.D in 2008 in applied physics. Since 2013 he has been working on embedded systems in the industrial sector. Since 2018 he has been a Game Designer. He is currently a researcher at the Department of Computer Science UNIMI and is responsible for the GSRC commission.

Liliana Silva - Liliana Silva is Associate Professor of Experimental Pedagogy at the Department of Education and Human Sciences of the University of Modena and Reggio Emilia, she mainly deals with the issues of assessment applied to lifelong and lifewide learning contexts and playful evaluation approaches.

Alessandro Rizzi – Alessandro Rizzi is Full Professor at the Computer Science Department of the University of Milano. He has been doing research since 1990 in the field of digital imaging with a particular interest on colour, visualization, photography, HDR, and on the perceptual issues related to digital imaging, interfaces and lighting.

Licensing terms

References

Armellin, L., A. Plutino, and A. Rizzi. (2022) ‘Online games for color deficiency data collection.’, RESEARCH CULTURE AND SCIENCE BOOKS, 6, 79-86.

Birch, J. (2012) ‘Worldwide prevalence of red-green color deficiency.’ JOSA A: 313 - 320. Color and Colorimetry. Multidisciplinary contributions. Vol. XVIII B ISBN 978-88-99513-24-5

Birch, McKeever, (1993) ‘Survey of the accuracy of new pseudoisochromatic plates’ Ophthalmic and Physiological Optics: 13(1), 35 - 40.

Cole, B. L. (2007) ‘Assessment of inherited colour vision defects in clinical practice’. Clinical and experimental optometry: 90(3),157 - 175.

Dobble, Denis Blanchot, Jacques Cottereau, Guillaume Gille-Naves, Igor Polouchine (2009)

Fantascatti, Jacques Zeimet (2010)

Nimble, Peter Jürgensen (2018)

Speedcolor, Erwan Morin (2017)

Wright, W. D., e L. C. Martin. (1946) ‘Researches on normal and defective colour vision.’ Optometry and Vision Science, 24(6), 311-312.

KONICA MINOLTA

NEW

Spectrophotometer CM-17d

Colour precision at your fingertips

Accurate measurements of colour with our new portable spectrophotometer CM-17d, with an integrated viewfinder camera

RETHINK PRECISION.

Giving Shape to Ideas