Color and Colorimetry
Multidisciplinary Contributions

Vol. XVIII A

Edited by Albana Muco and Filippo Cherubini

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ASSOCIAZIONE ITALIANA COLORE

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15-16 September 2023

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Presentation

The Color Conference, organized annually by the Gruppo del Colore – Associazione Italiana Colore, has reached its 18th edition in 2023 and was held at Milan Polytechnic branch of Lecco.

This two-day international event featured three invited speakers – **Andrew Stockman**, **Christopher Bauder**, and **Raimondo Schettini** – and the presentation of 70 papers.

The two volumes published in open access – one with 29 papers in Italian and the other with 34 in English – collect the papers presented on September 15th and 16th and are organized as follows: the chapters are grouped and follow the numbering in ascending order of the topics of the Call for Papers.

Finally, the "Color Award/Premio Colore 2023" was awarded to **Gaetano Pesce**. We would like to extend special thanks to the Color Committee – in the persons of Alice Plutino, Eva Mariasole Angelin and Miguel Ángel Herrero Cortell – for their valuable contribution and to Renata Pompas for memorably introducing Pesce at the conference.

Our gratitude goes to Andrea Siniscalco, *chair* of the Conference, for the great work done and to all those who participated, helped and collaborated in the successful realization of the event.

We hope you have a happy reading.

Albana Muco and Filippo Cherubini
December 2023

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Invited speakers abstracts

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Cone fundamentals, colour matching and individual differences

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Extended Abstract

At its input, daytime colour vision depends on the activations of just three photoreceptor types: the long- (L), middle- (M) and short- (S) wavelength-sensitive cones, each of which responds to light univariantly (*i.e.*, with regard only to the number of photons absorbed). Thus, a knowledge of the three cone spectral sensitivities allows us to predict pairs of lights that should appear the same to the normal or "standard" human observer. The CIE has sanctioned the cone spectral sensitivity estimates of Stockman, Sharpe & Fach (1999) and Stockman & Sharpe (2000) and their associated measures of luminous efficiency (Sharpe, Stockman, Jagla, & Jägle, 2005, 2011) as "physiologically-relevant" standards for colour vision (CIE, 2006). These discrete cone spectral sensitivities—often referred to as "cone fundamentals"—are specified for 2 and 10-deg vision for the mean "standard" observers with normal photopigment genotypes and with average ocular transparencies at 1 or 5-nm steps. These LMS cone fundamentals can be easily transformed into colour matching functions (CMFs) for other sets of primaries, such as XYZ (CIE, 2015) or RGB.

While it is important to be able to define the cone spectral sensitivity functions for the average or "standard" observer, it is becoming increasingly important to be able to predict those for individual observers many of which differ substantially from the average functions. Partly to facilitate this computationally, we have developed formulae that account for the three cone spectral sensitivities, their underlying photopigment spectra and the macular and lens pigment optical density spectra as continuous functions of wavelength from 360 nm to 850 nm with minimal error. These continuous functions enable individual differences to be easily calculated and allow the straightforward generation of non-standard cone spectral sensitivities (and other CMFs) with different macular, lens and photopigment optical densities, and with spectrally shifted L- and M-cone photopigments, such as those found in red-green colour vision deficient observers (Stockman & Rider, 2023). A Python program that can be used to easily perform these calculations has also been provided (https://github.com/CVRL-IoO/Individual-CMFs.git).

In a recent series of experiments done in collaboration with Ronnier Luo's group at Zhejiang University, we have used these continuous functions to analyse colour matches obtained with a new 18-primary LED-driven colour matching device (LEDMax®) produced by Thouslite, and from those matches have been able to identify the causes of the individual variation in a large group of colour normal and colour deficient observers.

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Colored light as a material

Christopher Bauder
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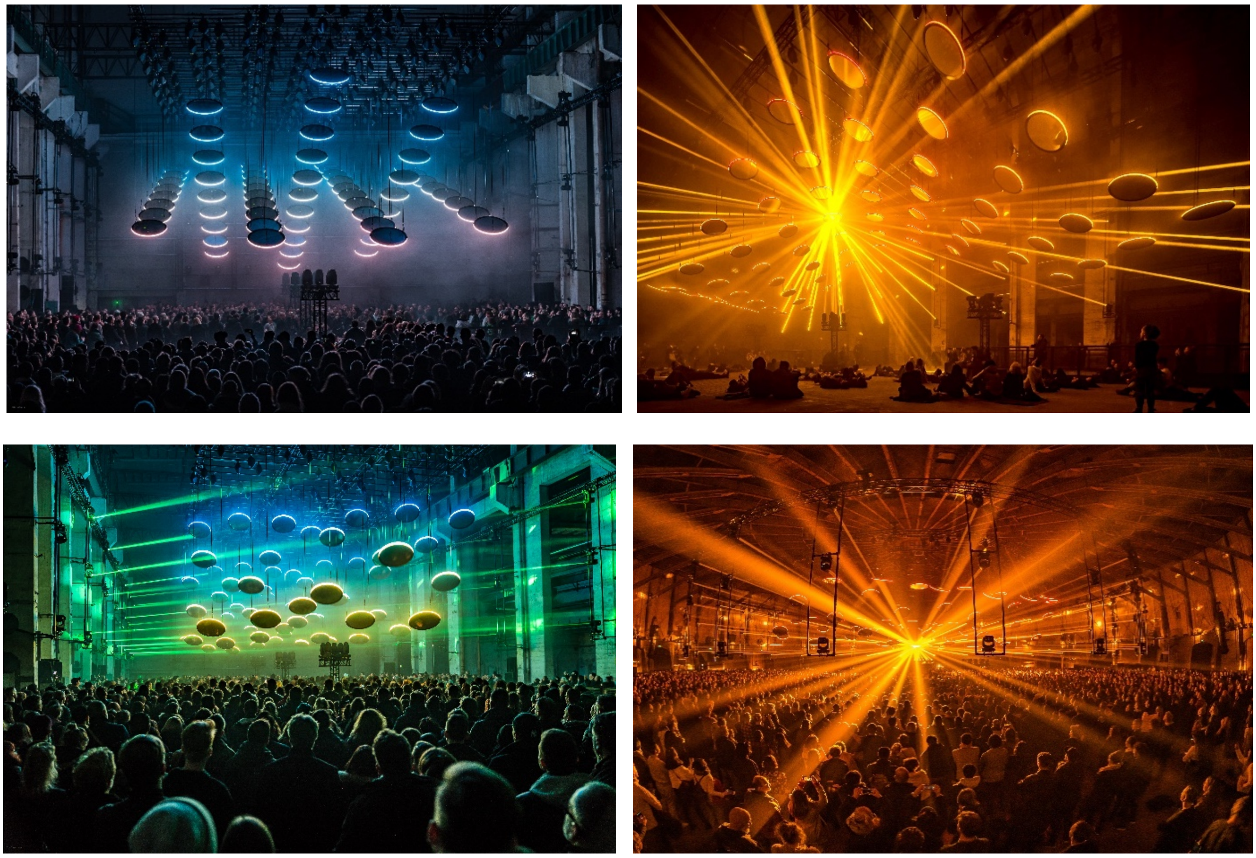
Abstract

In this lecture we invite you to explore the role of light and color in art and life. Light artist Christopher Bauder will present his work and his approach to creating captivating visual experiences with colored light. Bauder will demonstrate how light is not only an aesthetic component, but a strategic device for eliciting and influencing emotions. He will reveal how he employs light, color and motion to craft immersive installations that resonate with the audience on a profound level. You will witness examples of his remarkable work and learn how he integrates art, science and technology to realize his artistic vision.



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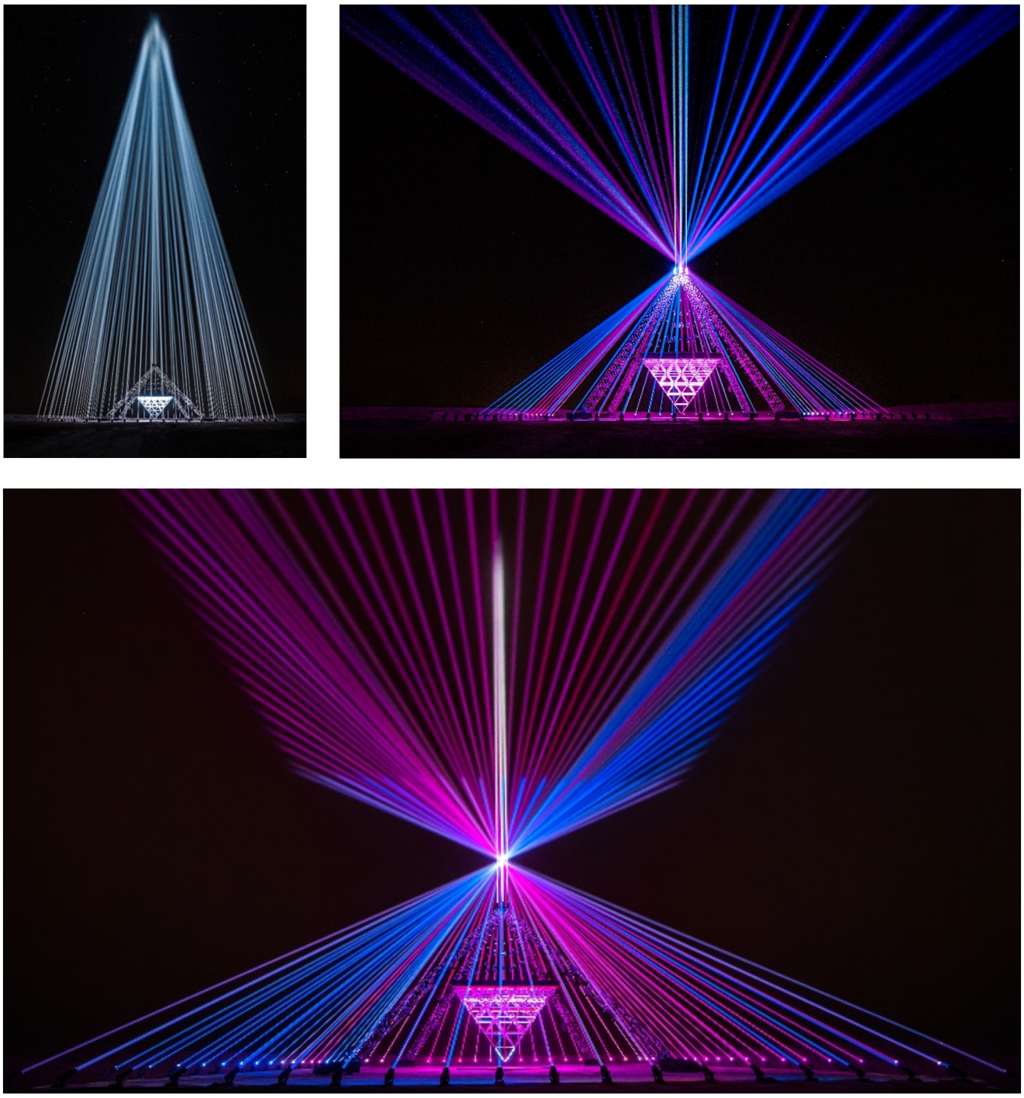

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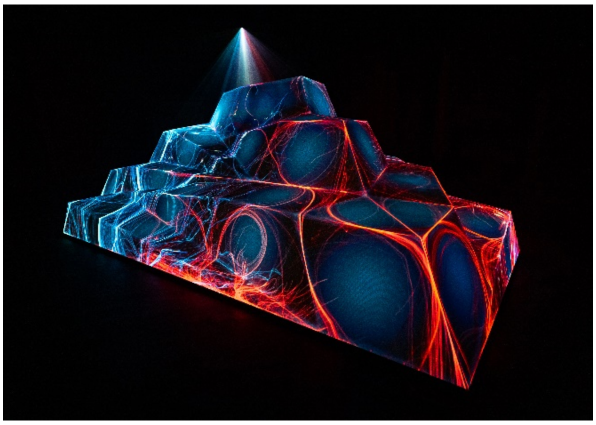
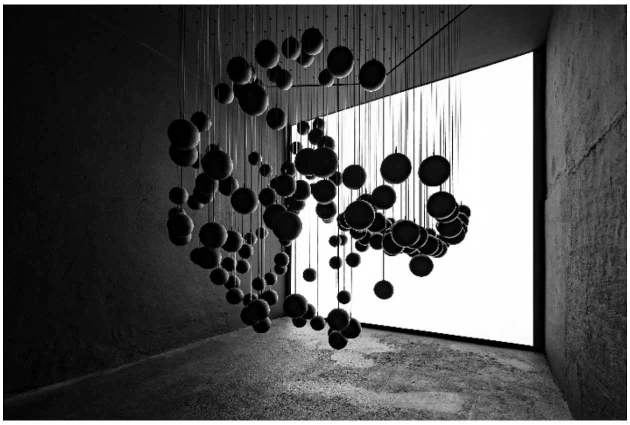
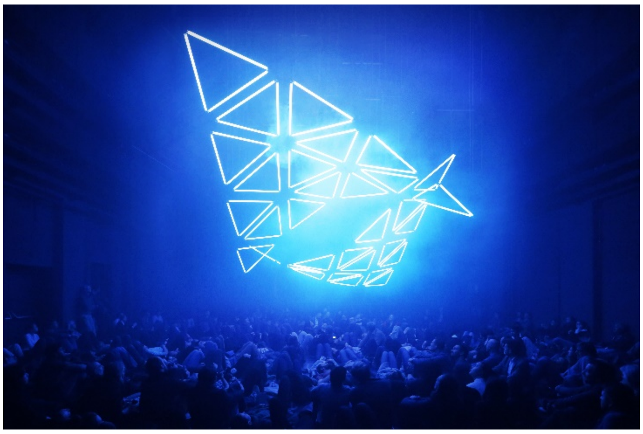

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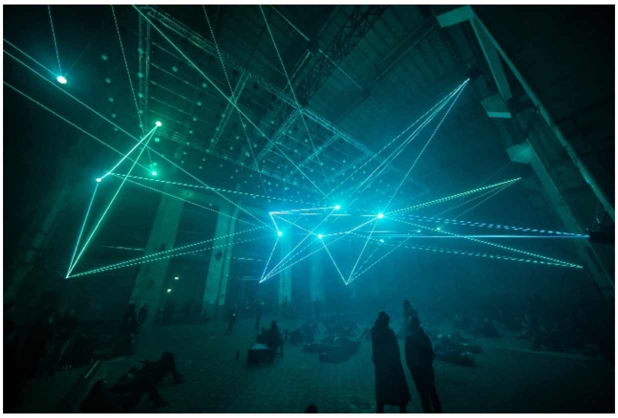

DEEP-WEB_Christopher-Bauder_photo by Ralph Larmann

LICHTGRENZE_Christopher-Bauder_Photo by Ralph Larmann

Data visualization with the help of color

Raimondo Schettini
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Abstract

In today's data-driven world, the ability to effectively communicate complex information is a crucial skill. One of the most powerful tools at our disposal for conveying data insights is color. This talk aims to explore the role of color in data visualization, specifically focusing on its application without subjective interpretation. We investigate the fundamental principles and techniques behind utilizing color to create impactful data visualizations, we discuss categorical color coding for representing discrete data, and sequential color coding for ordered data. The talk delves into practical examples demonstrating how color choices can impact the interpretation of data to demonstrate that only with an appropriate use color coding we can effectively communicate variations, trends, and patterns in the data.

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1. Color and Measurement/Instrumentation

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The Use of Colour Names Over Repeated Trials

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Abstract

Speakers group colour stimuli into categories that are commonly referred to by a name (e.g. *pink*, *peach*, and *pale green*). While the number of colour names in wide cultural use may vary across different languages, it has been shown that most languages have a small set of basic colour terms (BCTs) that are typically shared by speakers. The cognitive role of BCTs has been a subject of ongoing debate, with some proposing that the existence of primary basic categories may depend on structural and functional properties of the visual system. In this study, we investigate the effects of the duration of the experimental task on the use of colour names. In a lab-based colour naming experiment, we asked 17 English speakers to give unconstrained verbal responses for 216 presented colour samples, presented randomly one at a time against 7 different backgrounds. Test stimuli were 2 degrees uniformly coloured discs with a black outline of 1 pixel. The 216 colour stimuli were uniformly distributed in the CIE LMS parallelepiped. We collected a total of 26,504 unconstrained colour name responses. First, we consider the global entropy of the distribution of responses as a measure of all participants' colour vocabulary richness. We use the order of appearance of the backgrounds to group the responses in 7 bins and measure the entropy of colour naming responses for each bin. Our results show that the richness of colour vocabulary decreases as a function of the task duration. Second, we examine which colour names became more prevalent over trials as the vocabulary became impoverished. We found a positive correlation (R^2 = 0.8) between the use of BCTs and time-on-task, and a negative correlation in the case of non-BCTs (R^2 = -0.5), supporting that BCTs are easier to name than non-BCTs. However, across participants secondary basics have been used significantly more often (n = 5: *brown, orange, grey, purple,* and *pink*) (M = 1039, SD = 67) than primary basics (n = 6: *black, blue, green, red, yellow,* and *white*) (M = 773, SD = 49) over each of the 7 ordered backgrounds, $t(12) = -8.48$, $p < .001$, suggesting that secondary basics overall may cover larger regions of the cone excitation space than primary basics. Consistent with this explanation, a Pearson analysis showed a strong correlation (R^2 = 0.6) between frequency of BTCs and their corresponding volume in LMS cone excitation space.

Keywords: colour naming, task duration, entropy, basic colour terms.

Introduction

Across different languages, speakers possess the ability to categorize colour stimuli into distinct categories that are commonly identified by corresponding colour names such as *pink*, *peach*, and *pale green*. While the fundamental ability to categorise colours is a universal trait, the lexicon of colour names may vary in both size and complexity from language to language. For instance, a free-naming experiment revealed that English speakers employ thousands (n = 1166) of distinct monolexemic and plurilexemic colour names when labeling online the 600 simulated Munsell samples (Mylonas and MacDonald, 2016). In contrast, using the same colour set stimuli, the Himba community, a remote population in Namibia, offered only 24 distinct colour terms (Mylonas et al., 2022).

Cross-language variation in colour lexicon highlights the intricate interplay between neurophysiological factors, ecological influences, and cultural dynamics that shape the human experience of colour. Remarkably, the study of cross-language differences in colour categories, dating back at least to the pioneering work of Berlin and Kay (1969/1991), has established a crucial framework for understanding the mechanisms underlying the formation and evolution of colour categorization. According to their infuential account, most languages include a stock of so-called *basic colour terms* (BCTs), a limited set of colour terms that are typically shared and comprehended well by most speakers. This framework employs specific criteria to narrow down the potential candidates for BCTs, which are: (1) being monolexemic, (2) being applicable to a broad category of objects, (3) having a distinct scope from any other BCT, and (4) being psychologically salient. Based on these criteria, there are around eleven BCTs for most major modern languages. In English, the BCTs are the six primary colours of Hering's Opponent Colour Theory - *red, yellow, green, blue, black,* and *white* - along with the secondary (*grey, orange, brown, pink,* and *purple*).

Berlin and Kay's comparative study also suggests that the number of BCTs within different languages increases over time in a highly structured and predictable manner, with primary BCTs typically emerging before secondary ones in the development of BCT categorization. The temporal primacy of primary BCTs has often been explained in terms of perceptual salience and neurophysiological constraints (Hays et al., 1972; McDaniel, 1974; Kay and McDaniel, 1978). Recent research on infants' systems of colour categorization indicates that infants as young as four months exhibit categorical responses to colour stimuli, raising the possibility of an existing link between colour categorisation and the cone-opponent mechanisms in the retina. (Skelton et al., 2017). However, conclusive evidence for the existence of a biological basis for colour categories remains elusive.

Gibson et al. (2017) propose an alternative viewpoint for the inter-linguistic similarity found in colour systems. Based on experimental results showing a pattern of preference for warm over cool colour names, they suggest that the linguistic relevance of certain colour terms (and the way in which colour categories arise) depends on communicative needs rather than on neurophysiological properties of the visual system. Furthermore, recent findings have shown that the importance of primaries in the development of languages' colour lexicon may be overstated. Mylonas and Griffin (2020) make the claim that every class of colour categories should share some common characteristics and show that classes of primary categories are less coherent than classes of BCTs and achromatic colour terms (*white, black,* and *grey*).

In this study, we investigate the effects of the duration of the experimental task on the use of colour categories, with a focus on BCTs and the supposed subclasses of primary and secondary BCTs. The next section introduces and describes the experimental setup, and our results are presented and discussed in detail in the subsequent sections.

A Colour Naming Experiment

A laboratory-based colour naming experiment was designed to collect unconstrained verbal responses and reaction times to a series of 216 colour stimuli. The experiment involved the participation of 17 English speakers. The mean age of participants was 36 years (*SD* = 16.5 years), with females provided 59% of the responses, males provided 29%, and 12% identified as non-binary. Participation was voluntary and the experimental sessions were conducted after obtaining written *informed consent* from the participants (Varnhagen et al., 2005). Before running the experiment, all participants were screened for colour vision deficiencies using the City University Test (Fletcher, 1978). In recognition of their commitment, participants were compensated with cash for their time and effort.

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Colour stimuli were presented randomly, one at a time, on a calibrated CRT computer monitor against 7 different backgrounds. Throughout the experiment, participants adapted to 6 chromatic and 1 neutral, uniform, backgrounds, presented in random order. The test stimuli were 2 degree uniformly coloured discs with a black outline of 1 pixel. The 216 colour stimuli were uniformly distributed in the CIE LMS parallelepiped (CIE, 2006; Stockman & Sharpe, 2000). For each colour sample, the subject was asked to say out loud the colour name that she thinks best describes the colour sample and respond within 10 seconds for each sample. Notably, participants were free to use as broad or narrow names as they liked. We collected a total of 26,504 unconstrained colour name responses, using a head-mounted microphone to record the vocal responses.

The number of responses per name across all chips (global response rate) varied hugely. To give an example, the most frequent response (*pink)* was recorded 2733 times, hence a global response rate of 9,4%; while the least frequents (e.g. *neon salmon*) were produced only one, hence 0.003%. The final dataset encompassed a total of 675 distinct colour names. This included the 11 BCTs, 572 plurilexemic (more-than-one word) names and 92 monolexemic (single-word) but non-BCT colour names. When considering the frequency of these terms in the dataset, BCTs accounted for 54% of the colour lexicon, plurilexemics represented 32%, and monolexemic non-BCTs made up 14%. Notably, among the monolexemic non-BCTs, the most frequently occurring colour term was *turquoise,* a colour term often considered a potential candidate in the evolution of BCTs in languages of industrialized countries. (Zollinger, 1984, Mylonas and McDonald, 2016).

The Effects of Experimental Length on the Use of Colour Names

The first issue we wanted to address was how the duration of the experimental task impacted participants' colour vocabulary richness over time. We decided to use the global entropy of the distribution of responses as a measure of lexicon's richness. Drawing from classical communication theory, the entropy equation offers a way to quantify the total information content within a complete probability distribution of an event, based on its frequency (Shannon, 1948).

Our method involved dividing the series of experimental trials into seven distinct bins, each corresponding to a specific point in the experiment's timeline, determined by the order of background presentations. These bins served as a means to monitor the evolution of color vocabulary richness as participants devoted varying amounts of time to the experimental task. Subsequently, we calculated the entropy of colour naming responses for each of these bins (Fig. 1).

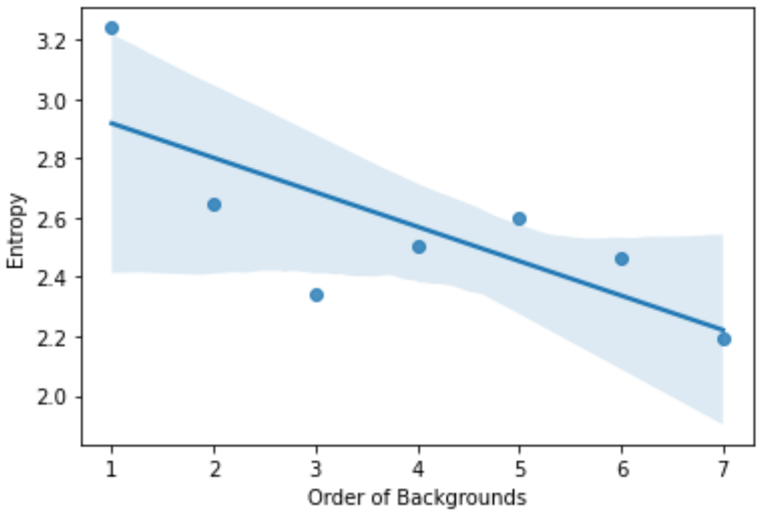

Fig. 1 – Richness of Colour Naming Vocabulary Over Repeated Trials

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Our analysis revealed a strong trend: the richness of colour vocabulary decreases as a function of the task duration (R^2 = -0.7). More precisely, the entropy values exhibited a peak of 4.3 bits during the initial bin of trials, signifying the highest level of colour vocabulary diversity at the outset. Conversely, as the task advanced, the entropy dropped to a minimum of 3.8 bits in the final bin, clearly indicating a reduction in the variety of colour names employed by participants. This observation underscores the profound influence of the length of the experimental task on participants' use of their colour lexicon.

The second issue we set out to investigate was which class of colour terms experienced a global increase in usage as the colour vocabulary became more limited over trials. Specifically, we want to compare the use of BCTs and non-BCTs (Fig. 2). We used Pearson's R correlation coefficient formula to calculate the strength of the association between the two classes of colour terms and the repeated trials of the experimental tasks. We found a positive correlation (R^2 = 0.8) between the use of BCTs and time-on-task, and a negative correlation in the case of non-BCTs (R^2 = -0.5). These findings align with the general claim that BCTs tend to be more prominent and easier to name compared to non-BCTs, and also support the idea of a certain level of independence between the richness and size of speakers' colour stimuli and how their perceive colour stimuli.

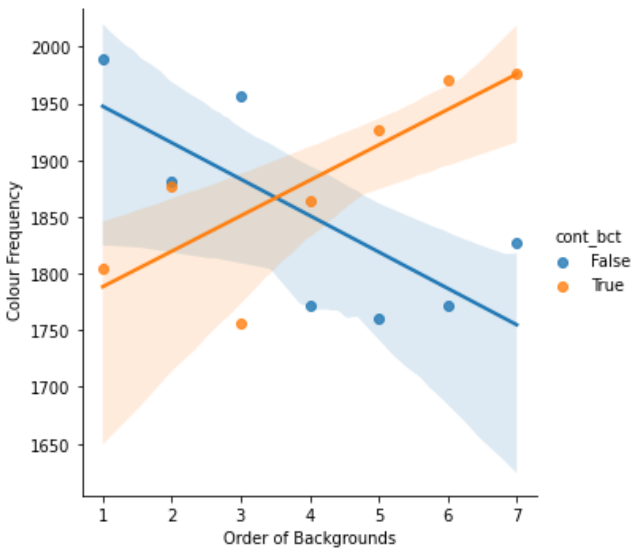

Fig. 2 – BCTs *vs* non-BCTs Over Repeated Trials

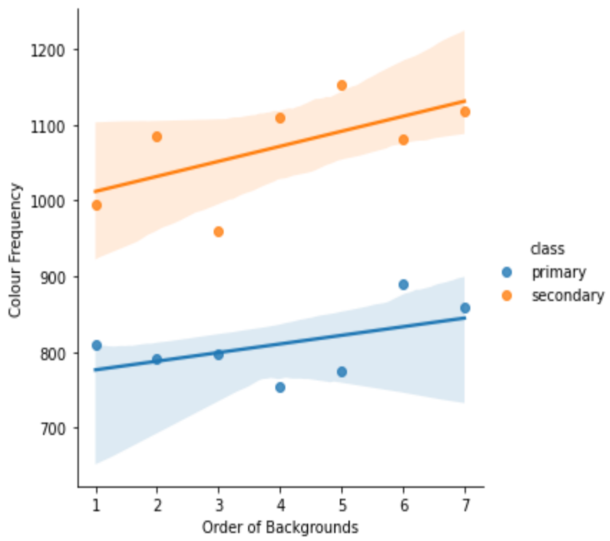

Fig. 3 – Primaries *vs* Secondaries Over Repeated Trials

Finally, we want to assess the hypothesized special status of primary BCTs in colour categorisation systems, by comparing the use of secondary BCTs and primary BCTs over trials. As shown above (Fig. 3), secondary basics were used significantly more often (*n* = 5: *brown, orange, grey, purple,* and *pink*) (*M* = 1039, *SD* = 67) than primary basics (*n* = 6: *black, blue, green, red, yellow,* and *white*) (*M* = 773, *SD* = 49) across participants. To confirm this trend, we conducted a t-test to compare the means of the frequencies of primary and secondary BCTs over each of the 7 ordered backgrounds, yielding a significant result ($t(12) = -8.48$, $p < .001$). These findings suggest the hypothesis that secondary BCTs may encompass larger regions of the cone excitation space than primaries in colour space. To assess this hypothesis, we use a Pearson analysis to examinate the relationship between the frequency of BCTs and their corresponding volume in LMS cone excitation space. (Fig. 4) Our analysis unveiled a positive correlation (R^2 = 0.6), which challenges the notion of primary BCTs holding a superior status in colour categorisation systems.

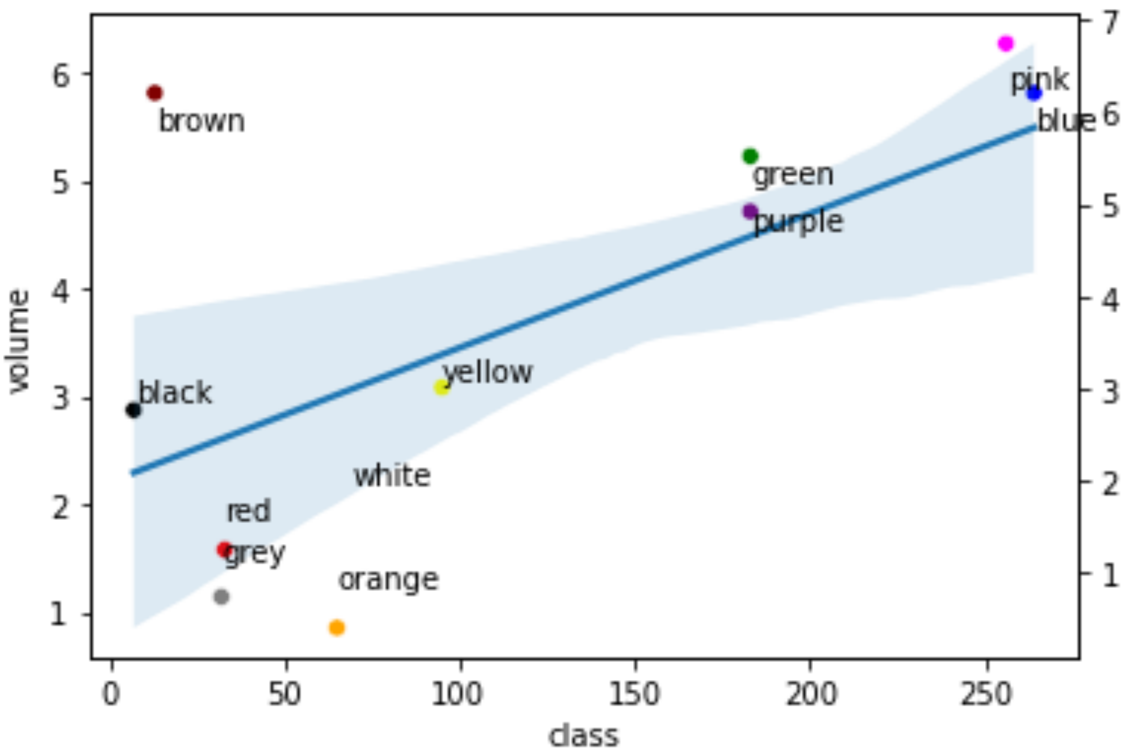

Fig. 4 – Relationship Between Volume and Frequency of BCTs Across All Trials

Conclusions

Based on a dataset collected in a laboratory-based experiment, our study discusses the use of colour categories over repeated trials and offers insights to assess the role of specific classes of colour categories, such as BCTs and primaries. Both classes have been often thought to have a special status in colour naming systems, influencing the debate between universalist and relativist over colour lexicons across and within different languages. In our analysis, we initially sought to understand how the duration of this task influenced participants' colour vocabulary richness. Through the calculation of global entropy, we found that as the task progressed, the richness of participants' colour vocabulary exhibited a noticeable decline. Indeed, our investigation into the usage of color terms over trials uncovered interesting patterns. We observed that BCTs held a special place in participants' vocabulary, as evidenced by their increased usage over time-on-task. In contrast, non-BCTs displayed a negative correlation, supporting the notion that BCTs are easier to use than non-BCTs. Additionally, our analysis challenge the presumed primacy of primary BCTs, as secondary BCTs were used more frequently, suggesting their potential coverage of larger regions in the cone excitation space. This finding questions the hierarchical prominence of primary BCTs in colour categorisation systems.

One issue relevant for our discussion concerns how speakers store and recall memories of colour terms and to which level of accuracy. The discussion of the relationship between colour naming, memory and perception has been characterized by two main perspectives: one suggesting that an individual's colour lexicon is largely independent of how humans perceive and remember colour stimuli (Heider, 1972), and the other claiming that the process of storing a colour in memory often implies some level of linguistic categorization (Kay and Kempton, 1984). Recent research, however, has demonstrated that the size of a speaker's colour lexicon is closely linked to their ability to memorize colours but remains independent of low-level perceptual variations (Hasantash and Afraz, 2020). We aim in future study to address the effect of individuals' ability to memorize and store colour names in the memory on their use. In conclusion, this study aims to unveil the intricate relationship between linguistic categorisation and perception in the realm of colours.

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Analysis of the influence of the surface-structural characteristics of textiles on the spectral characteristics of color in digital InkJet printing

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Abstract

An analysis of the influence of the surface-structural and constructional elements of fabrics on the spectral characteristics and quality of color reproduction in digital printing is carried out. Woven fabric samples of the same raw material composition (100 % cotton) were used, of the identical terms in yarn parameters, but different in fabric construction. A three groups of samples are chosen: Broken Twill 5/1 Z, Multi-row Twill 21/21 Z and Regular Panama Pa 3/3. The fineness of the warp and weft yarns was 36 tex, the warp density in all samples was 24 threads/cm, while two different densities of weft were used–20 threads/cm and 24 threads/cm. The statistical method of image analysis of the digital image of the fabric in ImageJ program was used, in order to obtain the characteristics of the porosity, texture and roughness parameters. The samples were printed using digital InkJet pigment printing technology. The objectification of the color by spectrophotometric measurement was carried out on the printed samples. The colorimetric results are shown by placing the samples in the a*/b* color space. A comparative analysis of the color parameters of lightness L*, chroma C* and hue h° was carried out. Based on the comparison of the samples, the values of the total difference in color (dE) and the differences of the individual parameters dL*, dC* and dh were calculated considering the differences in structure, construction parameters and weft densities. A microscopic analysis of the prints was carried out with a Dino-Lite Premier AM-7013MZT digital microscope, which confirms the interaction of the fabric structure and the color obtained by printing.

Keywords: color/textile interaction, color reproduction, textile design, digital InkJet printing

Introduction

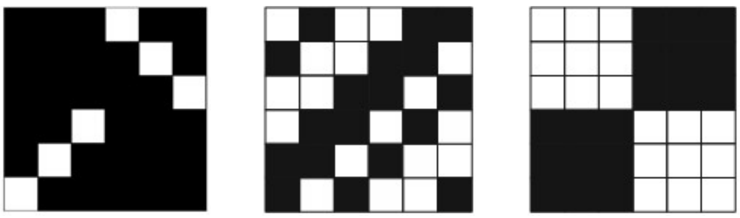
Digital InkJet printing technique was originally developed for homogeneous, uniform surface structures such as paper. However, textiles as a unique, heterogeneous, three-dimensional form is having its own surface irregularities. Due to its specific structure, textiles are coarse and porous compared to paper, which causes droplet deformation and a greater depth of ink droplet penetration (Gorji Kandi *et al.* 2008). The complexity of the textile material, meaning the geometric characteristics related to the textile surface, such as thickness, twist and the density of the yarn and fabric, inevitably affects the application of printing ink in digital textile printing and consequently the perception and appearance of the color on the textile surface. Also, the interaction of several factors with the diversity of the surface structure, as well as the diversity of the print and color relationship depending on the surface of the specific textile material affects the final appearance of a certain product. Therefore, research into color changes as a result of variations in the texture of the textile material is crucial. In the field of textile design, individual surface characteristics and the influence of the color of the substrate on the appearance of the product give authenticity to a quality textile product. Therefore, any study of the influence of surface structural characteristics of textile materials on print quality, contributes to the understanding of these fundamental mechanisms (Park *et al.* 2001; Tyler 2005, Tyler 2011; Bae 2015; Collis and Wilson 2012; Kuriki 2015; Parraman 2017; Kumah *et al.* 2020; Gooby 2020). In textile printing, it is necessary to understand the interaction of individual droplet of printing ink and different textile surfaces, which is essential in producing high-quality, well-defined images for a specific purpose (Polston *et al.* 2014; Kan and Yuen 2012). The complexity of the interaction of color and different media in inkjet technology was studied by Lavery and Provost (1999). The main variables in the digital printing system are: printing technology, physics of printing ink, interaction between dyes and textiles, preparatory phase and finishing. According to the literature, previous researches refer to influence of texture on color differences, simulated colored textures on a CRT screen and the influence of texture on the appearance of color in which real, physical (textile) samples (Moussa *et al.* 2008; Gorji Kandi *et. al*. 2008; Lee and Sato, 2001; Huertas 2006; Xin 2005; Yang, 2019). Research found in the literature confirms the significant influence of texture as a parametric factor which affects the color of the sample both instrumentally and visually but the quantity and quality of this effect is not yet well understood. The research presented in this paper analyzes the interdependence of the reproduction quality and appearance of the color, depending on the different structural characteristics of the textile and two different densities of the weft of the fabrics. The aim of the research is to contribute to the understanding of the fundamental mechanisms of the interaction of dyes, color and textile substrates.

Materials and Methods

Samples of textile fabrics with a raw material composition of 100% cotton were used. The samples were purposefully produced by the Croatian manufacturer of fabrics Čateks Industry, using identical yarns, but varying in construction characteristics, which resulted in fabrics of different structures and textures. Three different constructions are applied in the weaving process: Broken Twill 5/1 Z, Multi-row Twill 21/21 Z and Regular Panama Pa 3/3. The structural-mechanical parameters of the fabrics are shown in Table 1, and the schematic view of the weave constructions is shown in Figure 1.

Table 1. Structural-mechanical parameters of selected fabrics

Samples	**The fineness of the warp [tex]**	**The fineness of the weft [tex]**	**Warp density [threads/cm]**	**Weft density [threads/cm]**	**Mass [g/m^2]**
1A Broken Twill 5/1 Z - 20	36	36	24	20	154,32
1B Broken Twill 5/1 Z - 24	36	36	24	24	170,2
2A Multi-row Twill 21/21 Z - 20	36	36	24	20	154,1
2B Multi-row Twill 21/21 Z - 24	36	36	24	24	169,5
3A Regular Panama Pa 3/3 - 20	36	36	24	20	154,12
3B Regular Panama Pa 3/3 - 24	36	36	24	24	174,8



1. **2.** **3.**

Figure 1. Construction weaves of selected fabrics: sample: (1) Broken Twill 5/1 Z; (2) Multi-row Twill 21/21 Z; (3) Regular Pa Panama 3/3

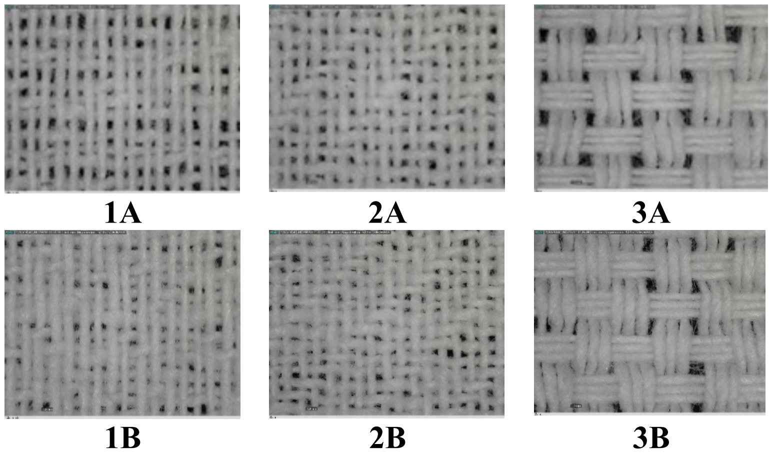


Figure 2. Microscopic images of samples structure

The structure of the samples is observed, also, by digital microscope imaging. The microscopic images are shown on Figure 2.

In the next step, using the method of image analysis in the ImageJ program, results on fabric porosity, texture and roughness using experimental method were obtained. In order to do so, the digital images of the samples were converted into binary images in order to calculate the percantage of white surface (meaning yarn spacing i.e. porosity) and black surface (the fabric excluding yarn spacing).The results were obtained using the Analyze > Measure command.The binary images of the samples form ImageJ program are shown on Figure 3.

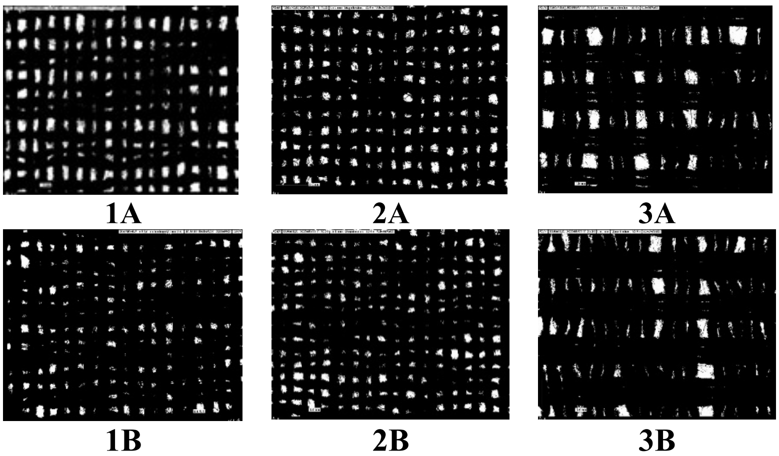


Figure 3. Binary images of samples analysed in ImageJ program

GLCM Texture and *SurfCharJ 1q* plugins were used to obtain data, i.e. parameters describing the texture of fabrics and their surface roughness in ImageJ program. The parameters that provide information about the texture of the scanned fabrics, are presented in Table 3. The results of the parameters that describe the roughness of the samples are found in Table 4. In the following experimental work, InkJet digital printing of the samples was carried out. A multicolored image was created in Adobe Illustrator and afterwards printed on the textile samples on Brother GTX pro digital printing device. After printing, the samples were hot air-dried under conditions of temperature and time T=160°C, t=3 minutes. Figure of image created in AI is shown on Figure 4. The scans of printed images on three selected fabric are shown on Figure 5. The analysis was carried out by microscopic imaging with a DinoLite AM7013 digital microscope, which is shown on Figure 6. The following analyzes were performed on the printed samples: microscopic imaging with a Dino-Lite Premier AM-7013MZT microscope and spectrophotometric measurement of the color characteristics by remmission spectrophotometer DataColor 850, with measuring aperture size 2.5 cm and measurement geometry d/8°.

Figure 4. Image created in Adobe Illustrator

The miscroscopis images of printed colors on selected samples are shown on Figure 6, while the results of color objectification are shown by placing the color printed on the samples in a*/b* color space and by comparative graphic presentation of the objective values of the color parameters (lightness L*, chroma C* and hue h°) shown on Figures 7 and 8. Also the color difference is calculated according to two CIE formulae – CIE76 and CMC(l:c) which is also accepted by the ISO standard for color difference evaluation on textiles. The results are shown in Table 5 and 6.

Results and Discussion

By conducting an image analysis of the selected fabrics, an insight into the characteristics of their porosity, their parameters of textures and roughness were obtained. The results are shown in Tables 2, 3 and 4.

Table 2. White area percantage which presents yarn spacing i.e. porosity from ImageJ program

Samples	Area	Area (%)	Min Threshold	Max Threshold
3A Regular Panama Pa 3/3 - 20	93635	6.710	255	255
3B Regular Panama Pa 3/3 - 24	75964	5.520	255	255
2A Multirow Twill Z 21/21 - 20	104923	8.188	255	255
2B Multirow Twill Z 21/21 . 24	90810	7.093	255	255
1A Broken Twill Z 5/1 - 20	137251	10.712	255	255
1B Broken Twill Z 5/1 - 24	74618	5.828	255	255

Table 3. GLCM texture parameters from ImageJ program

Samples	ASM	Contrast	Correlation	IDM	Entropy
3A Regular Panama Pa 3/3 - 20	0.0013	91.827	0,00	0,231	7.500
3B Regular Panama Pa 3/3 - 24	0.0015	82.292	0,00	0,2455	7.294
2A Multirow Twill Z 21/21 - 20	0.0013	101.920	0,0012	0,2312	7.510
2B Multirow Twill Z 21/21 - 24	0.0015	79.882	0,0014	0,2459	7.328
1A Broken Twill Z 5/1 - 20	0.0010	130.696	0,0008	0,2067	7.877
1B Broken Twill Z 5/1 - 24	0.0014	84.225	0,0018	0,2374	7.301

Table 4. Roughness parameters from ImageJ program

Samples	Rq	Ra	Rsk	Rku	Rv	Rp	Rt
3A Regular Panama Pa 3/3 - 20	30.034	18.563	-1.996	6.810	0	255	255
3B Regular Panama Pa 3/3 - 24	25.975	15.805	-1.797	8.416	0	255	255
2A Multirow Twill Z 21/21 - 20	28.258	18.025	-1.739	6.266	0	255	255
2B Multirow Twill Z 21/21 - 24	26.232	16.330	-1.572	7.055	0	255	255
1A Broken Twill Z 5/1 - 20	33.479	22.239	-1.603	4.071	0	255	255
1B Broken Twill Z 5/1 - 24	23.273	14.474	-1.365	8.156	0	255	255

Porosity, texture and roughness are compared in two ways– regarding the same structure, but different weft densities (20 and 24 threads/cm) and with regard to different structure, but the same weft densities (20 and 24 threads/cm). When comparing different densities of the samples, the results show that the sample with higher density has lower porosity (Table 2). When comparing samples in different structures, the highest porosity has sample 1A. Table 3 shows the results of texture parameters. By comparing samples of different densities, and the same structure, the values of ASM, correlation, and IDM are lower in samples with lower weft density compared to samples with higher weft density for all three types of the weave. Contrast and entropy values are higher for samples with lower density compared to samples with higher density for all three types of weave. When comparing samples in different structures, 1A has the highest contrast and entropy value. Table 4 shows the values that describe the roughness of the samples. According to Ra value, the average roughness of the surface, when comparing the roughness of samples of the same structure in different densities, samples of lower density have higher roughness. According to the results when comparing the samples of different structures sample 1A is the roughest.

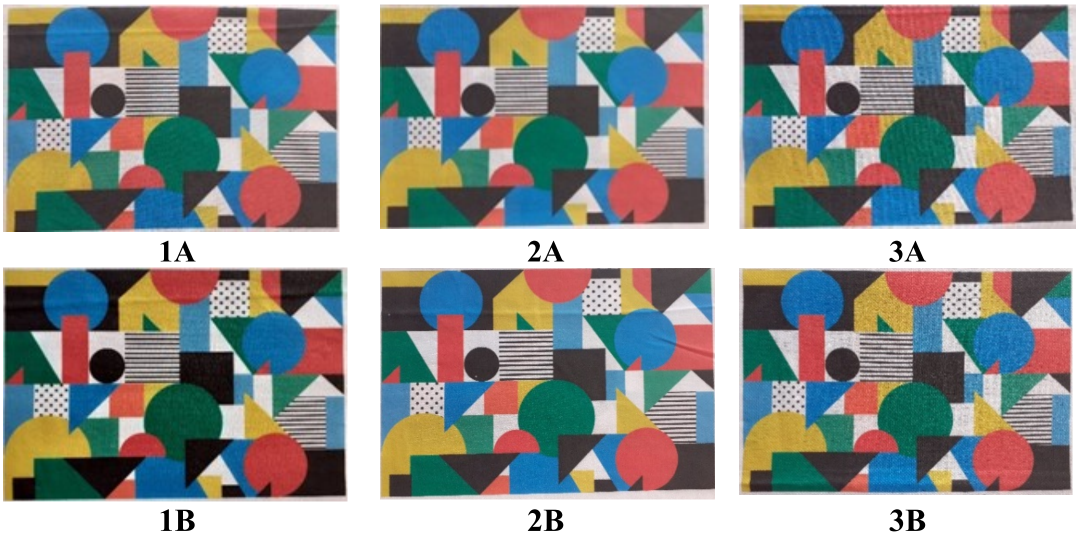


Figure 5. The scans of printed images on samples

Scans of printed images are shown on Fig. 5. and the microscopic images of printed samples are shown on Fig. 6. The interaction of the fabric structure and the color obtained by printing is visible. Irregularities in the mixing of process colors are also visible, which occur precisely because of the influence of the structure, which prevents proper positioning, and consequently the optimal mixing of process colors. The influence of the weaving points of the fabric is visible, and the places where there was no mixing of the process colors at all, but the points of the individual components are clearly visible (for example, in the case of green, the microscopic image clearly shows the positions where the mixing of the yellow and cyan process colors did not occur). Furthermore, bleeding of the printing ink is different in all samples; counturs of the objects are differently formed depending on the certain shape of the object (rounded, diagonal or straight) and the structure.

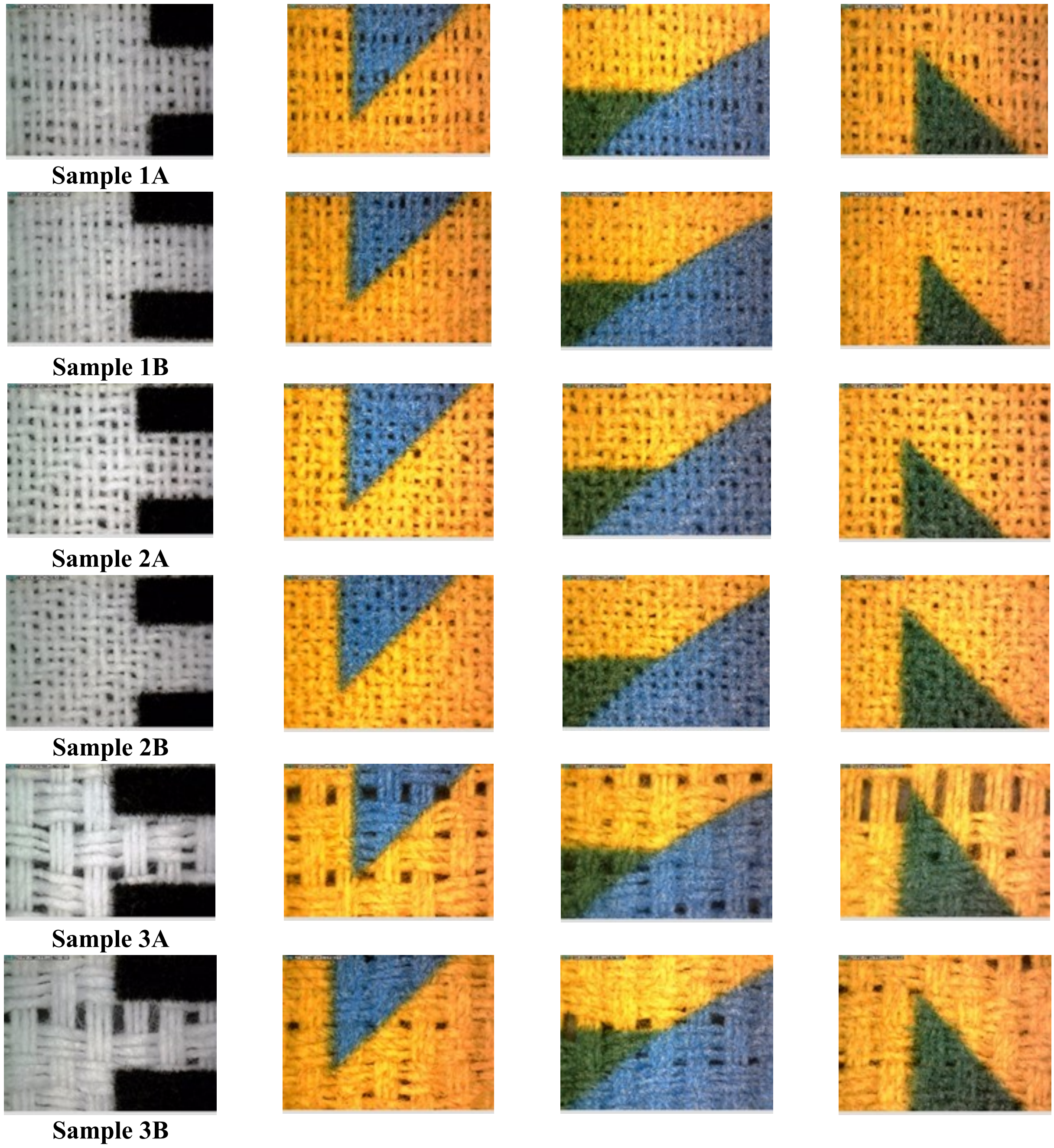


Figure 6. Microscopic imaging performed by digital microscope Dino-Lite

Spectrophotometric measurement of the color characteristics are shown on Figure 8 as a placement of a colors in a*/b* color space, and on Figures 9a-9c as comparative histograms showing lightness (L*), Chroma (C*) and hue (h°) changes for printed colors due to a different substrate structures. The results show slightly color differences which are within color tolerance acceptance limit according to ISO standard accept the 3° sample (0,87) in comparison to the standard 1A. However, it is observed when comparing samples of the same structure in different densities, that vaules of C* are higher in the higher densities for all colors.

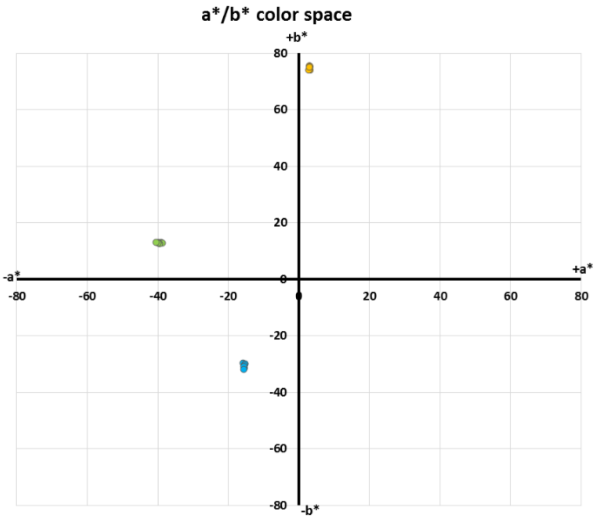


Figure 8. Results of spectrophotometric measurement: values of the printed samples placed in a*/b* color space

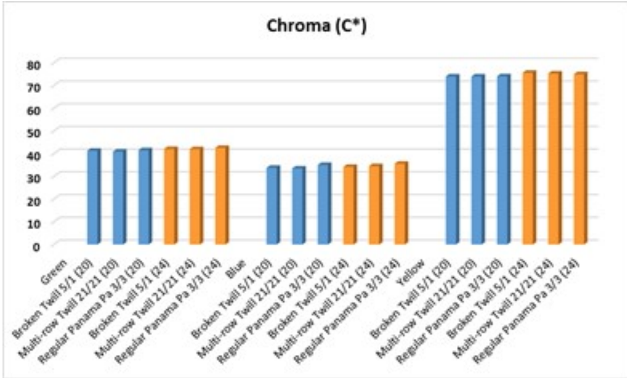


Figure 9a. Results of spectrophotometric measurement: values of parameters of Saturation (C*)

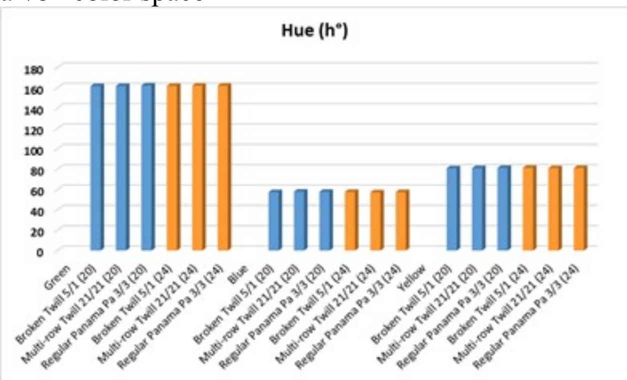


Figure 9b. Results of spectrophotometric measurement: values of parameters of hue (h°)

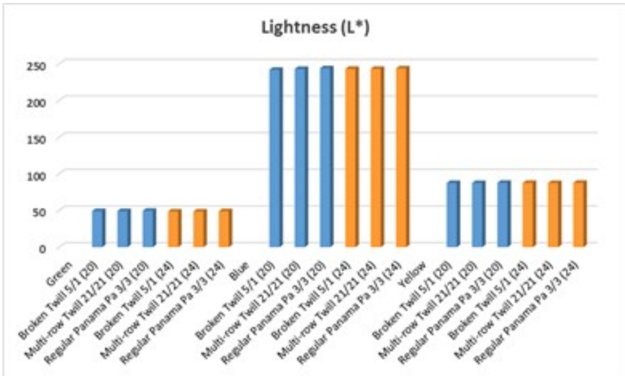


Figure 9c. Results of spectrophotometric measurement: values of parameters of Lightness (L*)

Namely, the surface structure and topographic characteristic of the textile will not affect the representation of wavelengths and the dominant wavelength in the reflected part of the incident light, which defines the color that the observer sees, i.e. its spectral characteristic. However, it will certainly affect the relationship and ratio of reflection, absorption and scattering of incident light, which will affect the appearance of the color, that is, the relationship between lightness and chroma.

Table 5. Color difference comparison of samples according to different structures in two densities: a) Density of the weft - 20 threads/cm b) Density of the weft - 24 threads/cm

Density 20 threads/cm	**CMC DE**	**CMC DL*/SL**	**CMC DC*/SC**	**CMC DH*/SH**	**Density 24 threads/cm**	**CMC DE**	**CMC DL*/SL**	**CMC DC*/SC**	**CMC DH*/SH**
Standard:		**Sample 1A_Green**			**Standard:**		**Sample 1B_Green**		
Sample 2A_Green	-0,01	-0,16	0,04	0,17	Sample 2B_Green	0,00	-0,03	0,11	0,12
Sample 3A_Green	0,23	0,10	0,28	0,37	Sample 3B_Green	0,19	0,21	0,09	0,30
Standard:		**Sample 1A_Blue**			**Standard:**		**Sample 1B_Blue**		
Sample 2A_Blue	0,21	-0,14	0,47	0,54	Sample 2B_Blue	-0,19	0,16	0,03	0,25
Sample 3A_Blue	0,13	0,60	0,87	1,06	Sample 3B_Blue	-0,08	0,64	0,28	0,70
Standard:		**Sample 1A_Yellow**			**Standard:**		**Sample 1B_Yellow**		
Sample 2A_Yellow	0,08	0,00	-0,05	0,10	Sample 2B_Yellow	-0,11	-0,11	-0,12	0,19
Sample 3A_Yellow	0,14	0,03	0,19	0,23	Sample 3B_Yellow	-0,04	-0,20	0,06	0,21

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Table 6. Color difference comparison of samples accordign to different densities: (a) green color; (b) blue color and c) yellow color

BLUE	CMC DE	CMC DL*/SL	CMC DC*/SC	CMC DH*/SH	YELLOW	CMC DE	CMC DL*/SL	CMC DC*/SC	CMC DH*/SH
Standard:	**Sample 1B_Blue**				**Standard:**	**Sample 1B_Yellow**			
Sample 1A_Blue	-0,1	-0,2	-0,5	0,5	Sample 1A_Yellow	-0,2	-0,5	-0,1	0,6
Standard:	**Sample 2B_Blue**				**Standard:**	**Sample 2B_Yellow**			
Sample 2A_Blue	0,3	-0,5	-0,1	0,6	Sample 2A_Yellow	0,01	-0,4	-0,02	0,4
Standard:	**Sample 3B_Blue**				**Standard:**	**Sample 3B_Yellow**			
Sample 3A_Blue	0,1	-0,2	0,1	0,3	Sample 3A_Yellow	0,01	-0,31	0,03	0,3

GREEN	CMC DE	CMC DL*/SL	CMC DC*/SC	CMC DH*/SH
Standard:	**Sample 1B_Green**			
Sample 1A_Green	0,25	-0,33	-0,06	0,42
Standard:	**Sample 2B_Green**			
Sample 2A_Green	0,24	-0,46	-0,14	0,54
Standard:	**Sample 3B_Green**			
Sample 3A_Green	0,28	-0,43	0,12	0,53

Therefore, under the influence of the surface structure, changes occur in the appearance of the color, which can be associated with the experience of a darker, lighter or more saturated color. Furthermore, it is essential to consider the nature of a single color when comparing its reproduction, appearance and color/structure interaction. When comparing samples of different densities/same weave, the values of contrast that is parameter of the texture and Ra / roughness are higher in samples of lower density/meaning coarser surface of the fabric. The comparison was made according to the CMC(l:c) system, which is accepted by the ISO standard for evaluating color differences on textiles. Results of color differences are shown in Table 5 and 6.

Conslusions

Complexity of color/structure interaction phenomenon depends not only on printing ink distribution, formulation and droplet formation, geometric characteristic of the fabric, but also incident light and different surface interrelations. Furthermore, physical an chemical characteristics of the pigments used in inkjet printing technology, inevitably affect structure and texture of the fabric; surface texture affects the color of the sample both instrumentally and visually, but this effect also depends on the nature of the color itself. Results in this paper confirm the influence of the structure/texture on the color reproduction and color appearance and influence of the fabric density on color saturation according to the spectrophotometric measurements. The interaction of the fabric structure and the color obtained by printing is visible on microsopic images; fabric texture affects the visual perception of color, but the quantity and quality of this effect is not yet well understood and investigated.

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An experimental analysis of the effect of color on human productivity and visual comfort in drawing workshop spaces using virtual reality

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Abstract

The present study investigates the visual comfort and productivity of the students when performing drawing activities under different wall colours through questionnaires and simulation experiments using virtual reality. In this research, tests in real and virtual scenarios of a drawing workshop room were performed, aiming to investigate the effect of three wall colours (red, white, blue) on human satisfaction with the indoor luminous atmosphere. To this aim, a combined method has been proposed: firstly, measurements in terms of luminance and illuminance level have been conducted in real space. Simultaneously to the measurement period a questionnaire was administered to 30 participants (students). The questions used in this survey were about satisfaction, brightness, glare, and occupation time. Secondly, the physical room was re-designed through virtual reality (VR) headsets to test the three colours, and finally, statistical analyses were performed to identify the responses of the occupants to changes in the wall colours and to compare results obtained in the physical and virtual environment. The results of this experimental study showed that wall colours have an impact on the user's visual comfort of the students in drawing workshop spaces and the participants' satisfaction is strongly influenced by their perception. The results showed that more than 63% of the participants were satisfied with the quality of daylighting in the virtual room with red colour. The study demonstrates also that the participants express a significantly higher occupation time (productivity) in the space with warm colours at low brightness than that of cool colours, regardless of the drawing activity performed. In addition, subjective evaluations obtained in both real and virtual rooms are mostly similar which confirms the ability of this method (VR) in the indoor lighting assessment.

Keywords: visual health, wall colours and hue, drawing workshop spaces, simulation experiments, field measurement, survey.

Introduction

Many researchers have shown that an appropriate indoor environment is an important issue for the visual health and productivity of users in workspaces (Choi *et al*., 2012; Hamedaniet *et al*., 2020). Among the many factors that impact students in workspaces, lighting seems to have the most influence. Visual comfort is an essential factor when designing interior colours for educational buildings, while the brightness and hue of colours are the factors that should be carefully studied to avoid discomfort (Kong *et al*., 2022; Krawczyk and Dębska, 2022). Moreover, the satisfaction of students with the built environment varies depending on their response to certain drivers, such as climate, contextual and personal parameters, indoor environmental quality, random, etc (Stazi *et al*., 2017; Daich *et al*., 2021; Hegazy et al. *et al*., 2021). However, under certain conditions, it isn't easy to create a physical environment with different variables under the same experimental conditions. To this aim, the use of virtual reality (VR) in the building makes it possible to facilitate the design, engineering, construction, and evaluation of the physical parameters of the built environment (Saadi *et al*., 2022; Marín-Morales *et al*., 2020; Newsham *et al*., 2010).

Several VR applications have been developed in the last two decades and are increasingly applied in the research area of human well-being, comfort, productivity, and behaviour in buildings (Latini et al., 2023). The VR technology has been used for lighting design to (i) study the indoor daylight

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quality, (ii) evaluate user perceptions, (iii) change space features, (iv) compare participants' assessment of the space with daylight indices, and (v) integrate virtual reality applications and daylight simulation engines (Mirdamadi *et al*., 2023).

The objective of this research is to study the relationship between the luminous environment and the productivity of students in drawing workspaces under three wall colours (red, white, and blue) using a combined method (questionnaire research and simulation experiments) using virtual reality.

Case study

The case study is located in Biskra (Algeria). It is situated in the southeast of the capital Algiers (Latitude: 34° 52′ North, Longitude: 5° 45′ East) on the border of the Sahara Desert (Fig. 1). The city of Biskra is characterized by hot and arid climate with a high exterior illuminance level exceeding 80000 Lux in July and an intermediate sky with an average annual cloud cover of around 40%, (Daich *et al*., 2017).

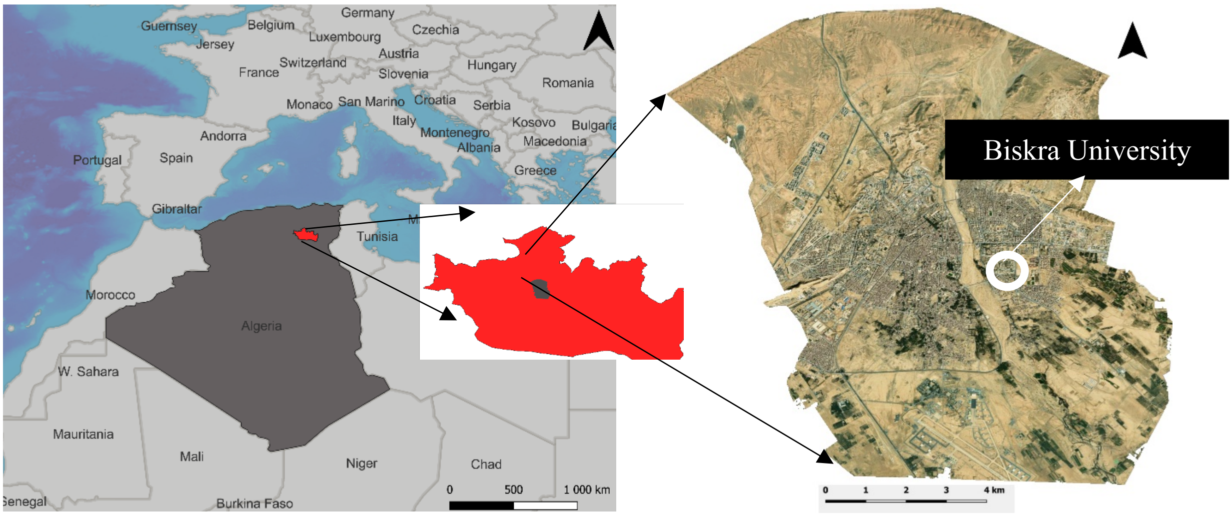

Fig. 1 – Case study location

The experiment was conducted in in real and virtual spaces representing drawing workspace in the department of architecture at Biskra University (Algeria). The workspace is situated on the ground level oriented to the north and has a rectangular shape of 7.50m wide, 14.00m length, and 4.50m high. The wall reflectances are represented in (Fig. 2). The room has two windows (1.20mx1.00m) located at 1.00m and another window (1.20mx 0.40m) situated at 2.00m. The space is occupied every Tuesday from 8.00 am to 11.00 am and from 1.10 pm to 4.20 pm.

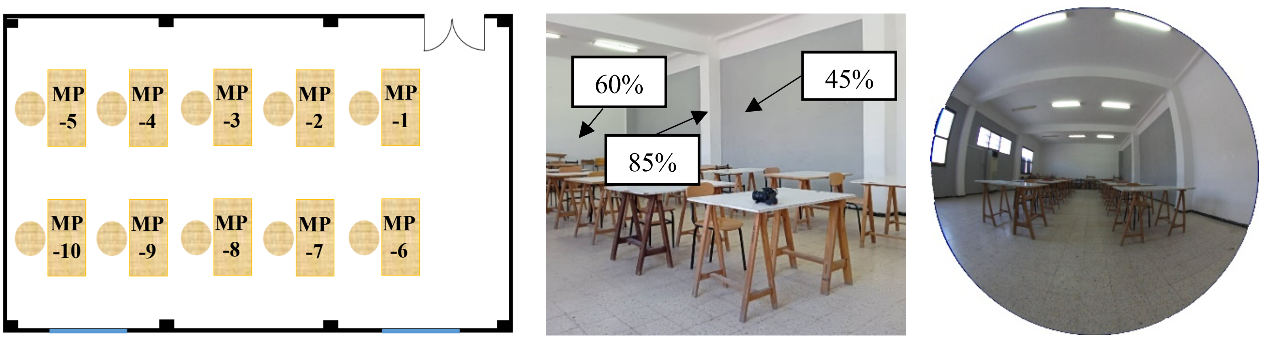

Fig. 2 – Workspace characteristics (real space)

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Materiel and methods

The methodology was designed to provide a direct comparison of the real and the virtual environments to investigate the effect of the wall colour on comfort, behaviour, and productivity. The objective is to detect any changes within the subjective responses due to the change in the tested environment and to study the adequacy of the virtual environment in daylighting research. These two methods have been employed: the first one is an experimental method used to collect a field measurement of the illuminance and luminance level in ten workspaces in the real environment (MP1-10). The second method is a questionnaire proposed to collect subjective data about the interior luminous atmosphere in real and virtual rooms. The survey was administered to thirty participants and had the purpose of obtaining subjective evaluations of lighting in different scenarios. The sample chosen was homogeneous in sex and age (50% female and 50% male) with an average age of 22. The student referred to their impression regarding (i) satisfaction and comfort, (ii) brightness and glare problems, and (iii) occupation time, at both morning and afternoon sessions.

The virtual model of the drawing workspace was created with DIALux 4.10 software. The 360 images were obtained by the superposition of several renderings using AutoPano software to enable the personal and immersive exploration of the environment in VR from the same point of view using a headset device (Fig. 3). Three different scenarios have been modelled: 1) room with red colour (reflectance 12%), 2) room with blue colour (reflectance 19%), and 3) room with white colour (reflectance 86%). The virtual rooms are presented in (Fig. 4). Another scenario has been proposed with the same colour in the real space to validate the qualitative results obtained in the virtual scenario. The experience was performed under natural lighting only without artificial lighting. The quantitative and the qualitative results obtained in both environments in the three scenarios have been correlated and analyzed to define the wall colour that ensures a comfortable space in drawing workspace rooms.

Fig. 3 – Virtual Reality (VR) headsets

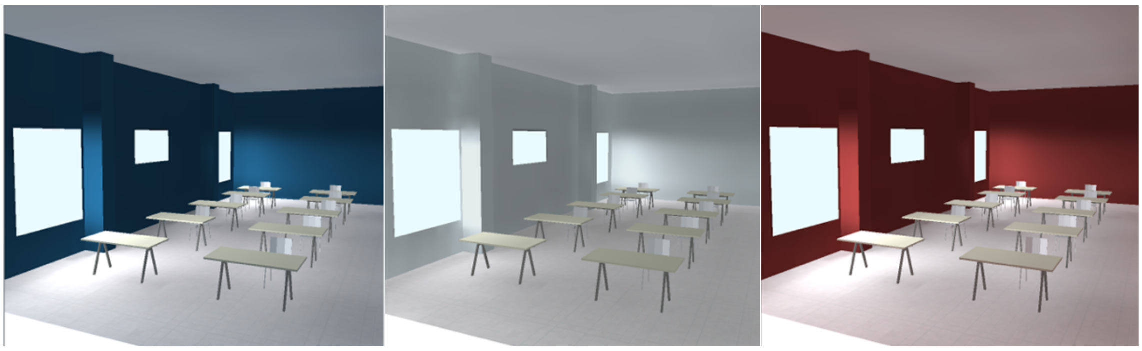

Fig. 4 – The three scenarios of the experience

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Results and discussion

Comparing the results presented in (Fig. 5), it is clear that the level of satisfaction of the students toward daylighting in both virtual and real environments is very similar, the values are in a range of ±5%. The participants presented the same appreciation in the morning compared to the afternoon where the responses were sometimes different. In conclusion, this experience confirms that virtual space can represent reality and can predict users' preferences in different daylight conditions.

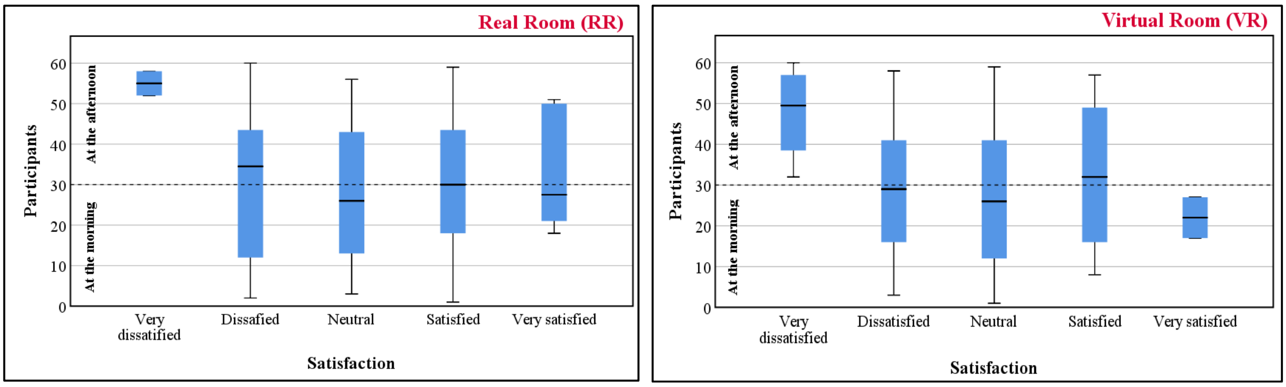

Fig. 5 – Satisfaction in real and virtual space

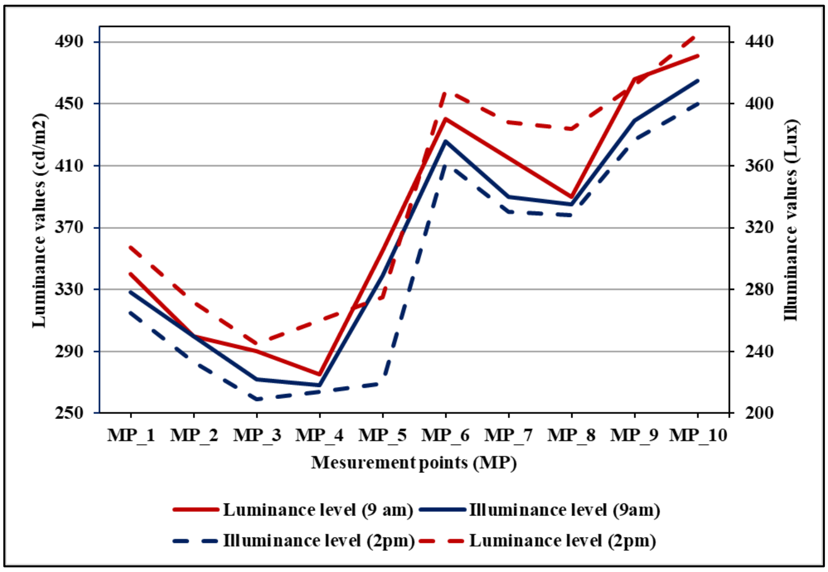

Fig. 6 – Field measurement results

The graphs presented in (Fig. 6) show that the maximum values were recorded in measurement points located near the openings (MP_7 to MP_10). At these points, the average illuminance values reached 415 lux in the morning and 400 lux in the afternoon, and the maximum values of the luminance are situated between 481 cd/m2 and 445 cd/m2 in the morning and in the afternoon respectively. The graphs show also that the average illuminance values recorded during the study hours reached 312 lux in the morning, whereas the lowest level was obtained in the afternoon with 209 lux. In addition, the average values of the luminance are situated between 340 cd/m2 and 375 cd/m2.

We conclude that the measurements of illuminance and luminance taken in the morning are acceptable compared with the values measured in the afternoon which are below the standard requirement in drawing workspaces (300-500 lux).

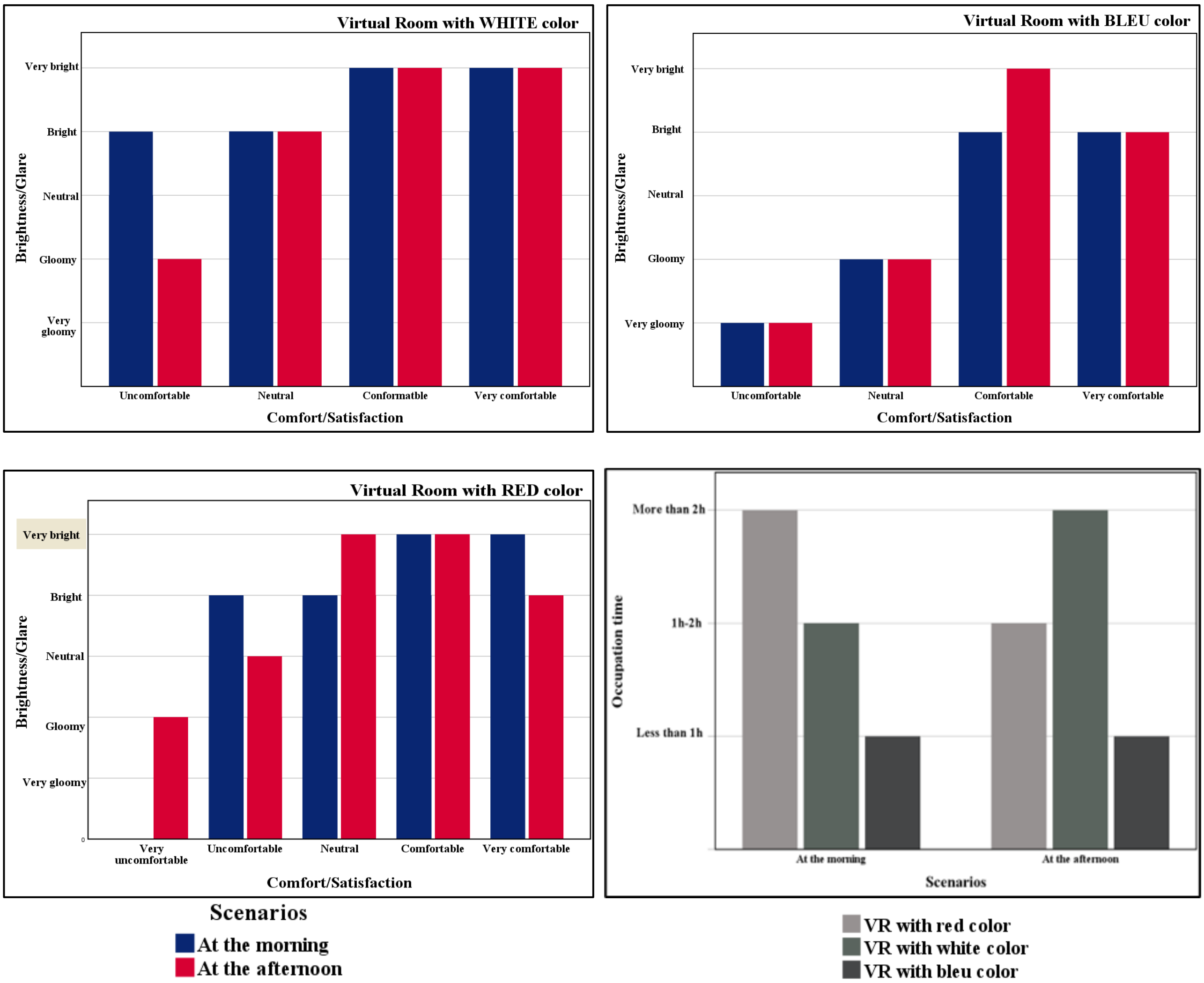

Fig. 7 – Questionnaire results

The graphs given in (Fig. 7) present the survey results of the satisfaction and comfort, brightness and glare problems, and occupation time administered to the students, in a virtual workspace room at both morning and afternoon sessions in the three scenarios. The comparison of collected data showed that the time of the day did not have a significant effect on the participants' perceptions while the responses were different regarding the wall color. The results indicate that the students felt more satisfied with the luminous atmosphere in the room with red and white colour compared with the blue colour. The results of the level of satisfaction reported by the students showed that 63.08% of the participants were more satisfied with the quality of daylighting in the virtual room with red colour, 56.44% in the white room, and just 39.84% of the subjects gave positive responses in the blue room. Therefore, the graphs indicate that the sensitivity to glare is the same in the red and white space (58.1% and 54.78%) and decreases in the third scenario (31.54%). Moreover, 9.96% of the participants felt very uncomfortable in the first scenario (red), 18.26% in the second (white), and 28.22% in the third (bleu).

In addition, the responses to the occupation time question showed that the productivity of students is the best in the red room compared with the other scenarios. Some 45% of the students can occupy the space for more than two hours, 20% in the white room and 18% in the blue room. The results can indicate also that the occupation time of the student is less than one hour in the blue room with 51.46% of the responses.

Conclusions

The objective of the present research is to study the effect of the luminous environment on the satisfaction and productivity of the students when performing drawing activities using a survey and immersive simulations. The comparison of the participant's evaluations of the luminous atmosphere in virtual and real space confirms the ability of the virtual reality tool to investigate daylighting in buildings. On the other hand, survey results showed that the subjects have the same appreciation at different times of the day (morning/afternoon) while the data indicate that the colour of the wall has a significant effect on the participants' perceptions where the majority of the students preferred the ambience generated by red and white colour. The findings indicate also that the best results were obtained in VR with red colour: more than 60% of the students felt more comfortable and more than 58% of the responses were positive regarding brightness and glare factor. The negative evaluations were given in VR with bleu colour, more than 28%). Moreover, the results showed that the productivity of students is higher in rooms with warm (red) or neutral (white colour) at low brightness compared to cool colours; more than 45% of the students can occupy the space for more than two hours.

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2. Color and Digital

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Prospects for the use of Artificial Intelligence for the choice of colors in the BIM methodology.

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Abstract
Using artificial intelligence for color choice in BIM methodology is a relatively new research field. Machine learning can be used to analyze the color preferences of designers and users and suggest appropriate color combinations for their designs. Some companies are working to develop Artificial Intelligence software specifically for choosing colors in BIM systems. The importance of the choice of colors in the BIM methodology has been recognized for some time, but only recently is it being thought of using Artificial Intelligence to help designers determine the color palettes for their projects, as in the relation between the digital representation of the colors of the project and the relationship with the actual colors. Using artificial intelligence offers many benefits, including the ability to analyze large amounts of data and suggest color schemes that might suit users' preferences. However, some challenges are associated with using artificial intelligence for color choice in BIM systems. For example, data analysis requires a large amount of computational resources, and interpreting the results can take time and effort. In summary, using artificial intelligence to choose design colors in the BIM methodology offers numerous opportunities and challenges. In this article, we propose a review of this sector and possible future developments.

Keywords: AI, BIM, color design.

Introduction

This article explores the emerging field of merging artificial intelligence and BIM methodology for color selection. While artificial intelligence in BIM is still relatively new, the benefits of applying machine learning to analyze designers' and users' color preferences to suggest suitable color combinations for their projects are recognized (Bassir *et al.*, 2023). The current research explores the current situation of dedicated artificial intelligence software for color selection in BIM systems. Although the importance of color selection in the BIM methodology has been acknowledged for some time, the idea of using artificial intelligence to assist designers in defining color palettes is recent. This article examines the relationship between the digital representation of project colors and their correspondence with actual colors, emphasizing the opportunity to leverage artificial intelligence. The benefits of using AI include analyzing large amounts of data and proposing color schemes in line with user preferences. However, challenges are associated with AI usage in color selection within BIM, such as computational data processing and understanding of results obtained. In summary, this article proposes a review of the sector, focusing on the opportunities and challenges offered by artificial intelligence for color selection within the BIM methodology. (Fig. 1).

Methods

Some studies have already highlighted the importance of the choice of color and finishes in the BIM system, emphasizing its impact on the resultant Color Harmony BIM (Lee, Kim and Hwang, 2019). In the realm of Building Information Modeling (BIM), current practices for managing colors and materials within projects primarily rely on traditional rendering techniques and Virtual Reality (VR) technologies without the integration of Artificial Intelligence (AI). Rendering, a cornerstone of architectural visualization, involves the meticulous configuration of material properties, textures, and lighting to produce realistic representations of architectural designs. Designers manually select and assign materials, adjust lighting, and fine-tune textures to achieve the desired visual outcomes. These processes are iterative and time-intensive, requiring expert knowledge of design aesthetics and rendering software. Concurrently, virtual reality technologies have gained traction for immersive design presentations. Designers can immerse themselves in 3D models and assess the spatial qualities, though the representation of colors and materials relies on manually defined parameters.

Some companies have already developed software specifically for color selection within BIM systems (Pasquale, 2022). For example, "Edificius" is an architectural BIM design software with an integrated "VRiBIM" feature, used to visualize the architecture and the design with an immersive and virtual reality technology integrated into BIM. Once immersed in the virtual environment, it is possible to gain a first-person perspective from within. Activating the menu with the left controller trigger enables us to select the 'change material' command. Through a few simple steps or with the help of a virtual keyboard, it is possible to access the online material catalog and select according to user preferences. Upon choosing the desired material, the user can apply it to the walls, unveiling the transformative impact that particular coloration imparts to the surroundings.

However, while current practices of rendering techniques and VR applications are effective, they lack the automation and data-driven insights that AI can offer in color and material selection. Incorporating AI into BIM promises to streamline these processes, enabling designers to leverage vast datasets and user preferences to generate harmonious and visually compelling color and material combinations efficiently. Nonetheless, traditional rendering and VR remain pivotal tools for design visualization, and the synergy of AI with these established techniques represents a promising frontier in architectural design and visualization.

AI can automatically generate unique combinations of colors and interior design styles. It can analyze extensive data on colors, design trends, and user preferences, generating aesthetically pleasing and cohesive combinations. This can be done by employing machine learning algorithms. Machine learning (ML) is a subfield of artificial intelligence (AI) that focuses on developing algorithms and statistical models that enable computer systems to progressively improve their performance on a specific task or problem through experience gained from data. It involves the automated discovery of patterns (Bishop, 2006), relationships, and insights from data, allowing machines to make predictions, decisions, or classifications without being explicitly programmed for each case (Hastie, Tibshirani and Friedman, 2009). Thanks to remarkable data and computational capabilities advancements in recent years, machine learning has become pervasive across various domains, even in our everyday experiences. It plays a role in diverse applications, such as identifying email spam, enhancing search result rankings, suggesting videos and posts, and enabling language translation. (Yao and Zheng, 2023)

To suggest an appropriate color for a specific element of the project, such as floors, walls, ceilings, and types of furniture, it is essential that the system correctly and automatically recognizes those elements. Therefore, an automatic semantic segmentation is needed. Different studies have shown that Deep learning (DL), a subfield of ML (Goodfellow, Bengio and Courville, 2016), can efficiently help the machine to develop this time-consuming process. Prior research demonstrated the capability of Deep Learning (DL) to construct a BIM model from images sourced from diverse devices. (Obrock and Gülch, 2018). Mechanisms that identify materials in an image have been studied, useful in BIM and the automatic enrichment of images (Dinis *et al.*, 2022).

Furthermore, investigations revealed the potential of scanning 2D images while capturing RGB-D data, encompassing color and Depth details. (Czerniawski and Leite, 2020). DL also empowers the analysis of a 3D openBIM IFC file, enabling the extraction of geometric and prevailing color data." (Zhai *et al.*, 2022)

Results

Outside the realm of BIM, there have long been tools available for designers that suggest color palettes for use in interior design projects. However, not all of them use recent AI to propose solutions. Nevertheless, some of them employ algorithms and advanced data processing techniques that can be regarded as forms of artificial intelligence. We can mention some of them: "Colormind" (*Colormind - the AI powered color palette generator*, 2023): Colormind uses machine learning algorithms to generate coherent and pleasant color combinations. "Adobe Color" (*Color wheel, a color palette generator | Adobe Color*, 2023): while not exclusively AI-based, Adobe Color incorporates some aspects of artificial intelligence in how it generates and suggests color combinations. "Coolors" (*Coolors - The super fast color palettes generator!*, 2023): Coolors employs an algorithm to generate harmonious color combinations automatically. "Canva Color Palette Generator" (*Color palette generator | Canva Colors*, 2023): Canva might use some AI techniques to assist in generating captivating designs and visual content, but it is not primarily AI-based. "Huemint" (*Huemint - AI color palette generator*, 2023) claims to be based on AI but is more suitable for designing brands, websites, or graphics. "Palette" (*Palette*, 2023) is another online tool that helps the user to colorize black and white photos or even change the color to some already colored pictures. However, it is based on user text-inputted prompts.

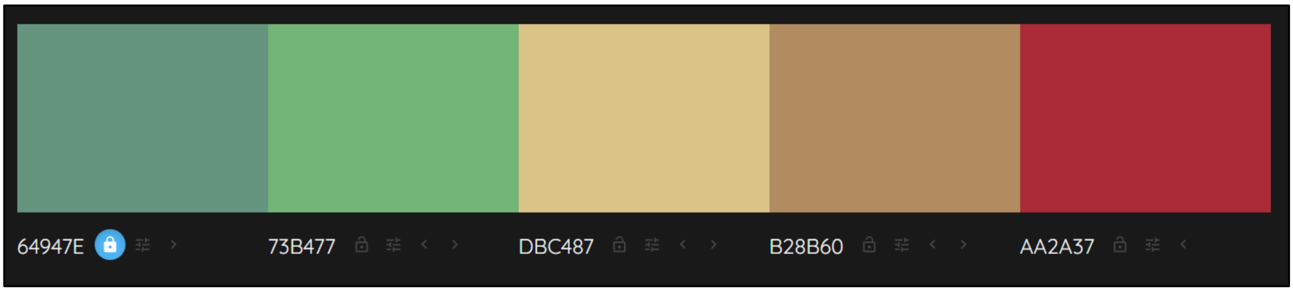

Fig. 1 – Harmonious color combination generated by Colormind.

"Colormind" is an AI-powered tool designed to assist designers and creators in generating cohesive and visually pleasing color palettes. Leveraging sophisticated machine learning algorithms, Colormind analyzes existing images or user preferences to propose harmonious color combinations (Fig. 1). The platform enables users to explore a wide range of color options, refine palettes, and even generate gradients. Colormind's intuitive interface encourages experimentation, allowing designers to effortlessly create captivating color schemes that align with their projects. Additionally, its integration with design software and ability to provide hex codes ensures seamless incorporation of chosen colors into various projects, whether for web design, branding, or visual content. It can also create a color palette from an uploaded reference image. Colormind streamlines the process of finding the right colors, making it an invaluable resource for enhancing aesthetic choices across diverse creative endeavors.

"Adobe Color" is a versatile online tool that empowers designers to explore, create, and fine-tune color palettes for their projects. Users can generate harmonious color combinations using various color rules and harmony types with an intuitive interface. Adobe Color also allows users to extract color themes from images, facilitating inspiration from real-world visuals. Designers can save and organize their palettes, and the integration with Adobe Creative Cloud ensures seamless use across Adobe's design software. Furthermore, the Explore section provides access to a diverse array of user-generated color themes for added inspiration. Whether for graphic design, web development, or branding, Adobe Color simplifies the process of selecting and refining color palettes, enhancing the overall creative workflow for designers.

"Coolors" is an online tool that simplifies color palette generation for designers and creatives. Coolors help users effortlessly create harmonious and appealing color combinations using advanced algorithms. The platform allows users to explore, customize, and refine color palettes in real time, making finding the perfect colors for projects more accessible. With features like color-locking, exporting to various design software formats, and integration with Adobe Creative Cloud, Coolors streamlines the color selection process. Whether for web design, graphic projects, or interior decor, Coolors empowers users to make informed color choices that resonate with their vision.

"Canva's Color Palette Generator" is a valuable tool that simplifies the process of creating harmonious color schemes for design projects. By analyzing uploaded images, the generator automatically extracts dominant colors and suggests complementary hues, enabling users to build cohesive palettes. Additionally, users can manually adjust colors, fine-tune shades, and lock specific tones to ensure the desired aesthetic. The tool also provides hex codes for each color, ensuring easy replication across various design applications. This feature is especially helpful for maintaining consistent branding. Whether for graphic design, website development, or marketing materials, Canva's Color Palette Generator streamlines the color selection process, allowing designers to quickly access visually appealing and balanced color schemes that resonate with their project's objectives.

"Huemint" is an innovative platform that utilizes artificial intelligence to revolutionize interior design. It provides users with cutting-edge tools and suggestions for color palettes, layout arrangements, and decor choices. By leveraging advanced algorithms and design principles, Huemint.com streamlines the decision-making process for designers and homeowners. The platform's AI capabilities analyze project requirements, user preferences, and spatial dimensions to propose personalized and aesthetically pleasing design options. With Huemint, the user can also create a colored version of a grayscale image, explore diverse design ideas, experiment with color combinations, and visualize their spaces before implementation.

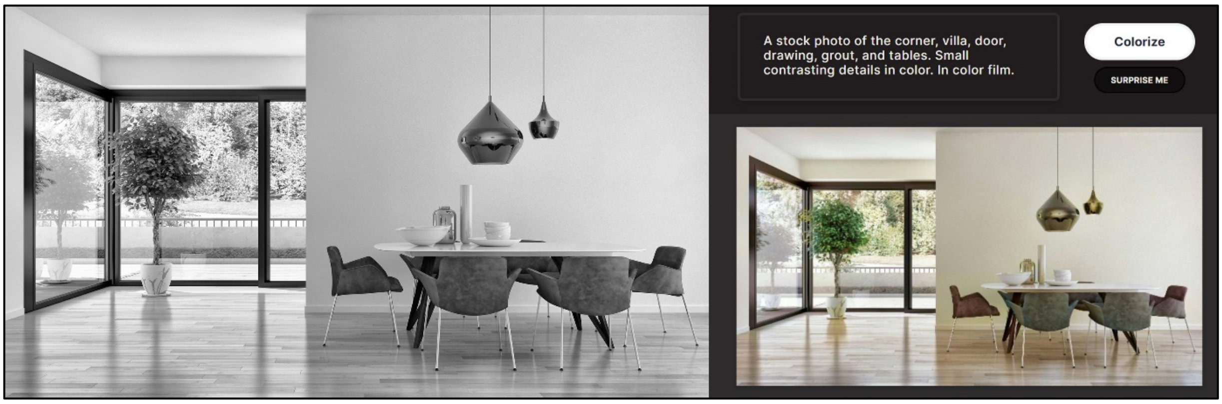

Fig. 2 – Palette.fm turned a black-and-white image into a colored picture. The user has given suggestions to the system through an input-prompt feature.

"Palette.fm" is a powerful online platform designed to simplify the process of color palette creation for designers, artists, and creatives (Fig.2). This intuitive tool leverages the principles of artificial intelligence and data-driven insights to assist users in generating harmonious and visually appealing color combinations. Palette.fm offers a range of functionalities that make it an invaluable resource for color selection and design projects. Users can explore a vast array of color palettes, each thoughtfully curated and inspired by various themes, moods, and aesthetics. The platform also provides tools to create custom palettes, enabling users to experiment with colors, adjust shades, and fine-tune their selections to align with their project's vision. One of Palette.fm's standout features is its ability to extract color palettes from images, allowing users to draw inspiration from real-world visuals. Additionally, users can save and organize their favorite palettes, streamlining their design workflows for future reference. Overall, Palette.fm empowers designers and artists to make informed color choices, fostering creativity and enhancing the visual impact of their projects. The user can also create a colored version of a grayscale image, but here it is possible to address the result by giving suggestions through the use of an input-based prompt system.

In the context of Building Information Modeling (BIM), Autodesk's Revit software plays a pivotal role, equipping architects and designers with a robust toolkit for intricate project management and design. Notably, two innovative plugins, "Veras" (*VERAS*, 2023) and "ArkoAI" (*ArkoAI*, 2023), have emerged, poised to revolutionize the process of color palette selection within the Revit ecosystem. Developed by EvolveLab, Veras employs AI to seamlessly transform 3D models into realistic visualizations driven by user prompts that enable precise color preference articulation. Conversely, ArkoAI introduces a novel dimension by enabling users to create AI-driven visualizations from Revit's perspective view, guided by user directives and even the capacity to save specific settings. Both plugins adeptly leverage user prompts to intertwine human preferences and AI-driven solutions within the color palette generation process. These prompts serve as dialogues with the AI system, facilitating the generation of color schemes aligned with project objectives, though further refinement may be required. Veras and ArkoAI exemplify the fusion of human creativity and AI, offering powerful tools for architects and designers to expedite color palette selection in the intricate domain of BIM.

EvolveLAb's "Veras" is an image generator derived from three-dimensional models and is available as a plugin for various applications, including the BIM software Revit. From the latter, designers can choose a perspective view, display it in a realistic mode, and customize it without performing any rendering. It is not a real-time plugin; changes to the view need to be manually updated afterward. Once the plugin is activated, users can employ a user prompt to input specific requests (Fig. 3). These requests can also involve materials, finishes, and colors. The system will then propose, following input from the designer, a starting image that aligns with the expressed preferences.

It should be noted that these indications can serve as inspiration for the designer's color choices, albeit only at the conceptual level. The final visualization will likely need to be redone, as the AI might inadvertently alter or misinterpret some aspects of the project. To avoid these errors, it is necessary to facilitate the AI's operation by providing the algorithm with as much information as possible to aid learning. For instance, the more semantically declared Revit objects are present, the more easily they will be recognized. The more materials are specified and applied to model objects, the better the AI will identify them and know where to intervene in various simulations. Another way to prevent these misinterpretation errors is to try to provide as detailed information as possible when entering prompts.

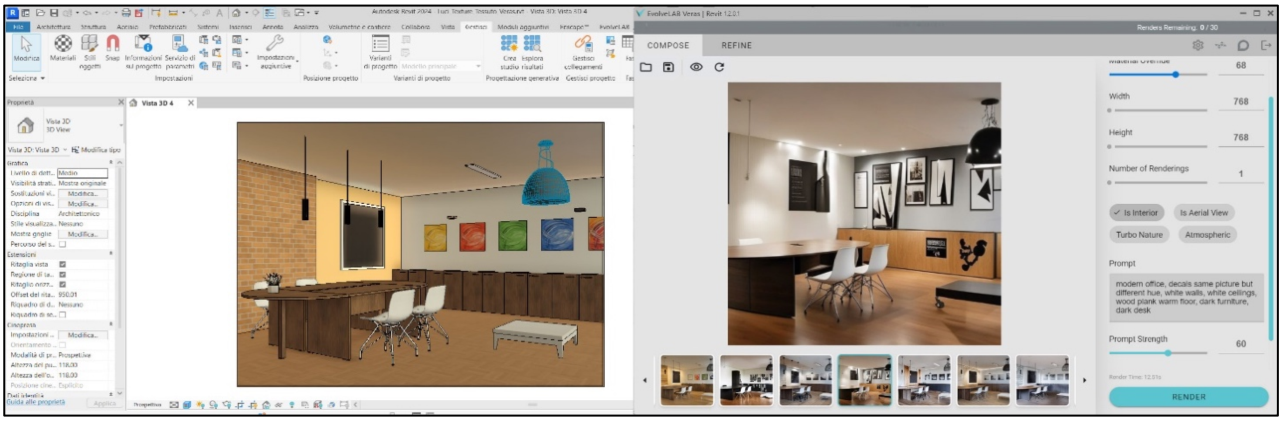

Fig. 3 – Vera, a plugin for Revit that generates AI visualizations based on semantic classification of the model and user input prompts requests.

In contrast, "ArkoAI" introduces a distinct dimension to the process of color palette generation within Revit. This plugin empowers users to engender visualizations through AI mechanisms, capitalizing on Revit's perspective view. The central role of user prompts remains integral to ArkoAI's operational framework. Designers can submit specific directives, elucidating project style, category specifications, and even exclusions via negative prompts. ArkoAI augments this functionality by incorporating the capacity to save particular settings through seed numbers, which can subsequently be invoked to produce images from alternative perspectives, further enhancing flexibility and control.

In summary, Veras and ArkoAI represent pioneering advancements within the context of Building Information Modeling (BIM). They provide architects and designers with powerful tools to streamline the complex process of color palette selection. These plugins effectively leverage user prompts, serving as a crucial interface that bridges the divide between human creativity and AI-driven solutions. This interaction facilitates the efficient creation of visually pleasing and harmonious color palettes within the Revit environment. In an era marked by rapid technological progress, Veras and ArkoAI exemplify the transformative potential that arises from the convergence of artificial intelligence with the creative insights and technical expertise of professionals in the field of architecture and construction.

Discussion

The application of AI in color selection within BIM introduces a paradigm shift in design processes. However, it is paramount to recognize and address the intricate challenges associated with this transformative technology. Notably, the computational data processing demands imposed by AI algorithms represent a substantial hurdle. The analysis of vast and diverse datasets, comprising color preferences, historical design trends, and user feedback, necessitates substantial computational resources. Architects and designers must grapple with the intricacies of managing these computational loads efficiently.

Additionally, interpreting results obtained from AI-driven color selection can be a nuanced endeavor. AI may generate color combinations based on mathematical and statistical patterns, which require scrutiny and validation for their appropriateness in specific architectural contexts. This involves deciphering how the AI interprets design aesthetics, user preferences, and contextual nuances. Achieving this level of interpretative transparency is pivotal for architects and designers to make informed decisions, refine AI-generated color schemes, and ensure their harmonious alignment with the overall architectural vision. Consequently, while AI holds the potential to revolutionize color selection within BIM, it is imperative to overcome these computational and interpretative challenges for its seamless integration into the architectural design process.

Conclusions

This article explores the intersection of artificial intelligence AI and BIM in the context of color selection. AI's potential to analyze user color preferences and propose suitable palettes in the BIM framework is emerging. This research evaluates existing AI software for color selection in BIM systems, highlighting the importance of this relatively recent development. In BIM, color and material management traditionally rely on rendering and VR, lacking AI automation and data-driven insights. The fusion of AI with these established techniques offers a promising frontier in architectural design, streamlining color and material selection by leveraging datasets and user preferences. Deep learning enhances AI's ability to identify elements, improving semantic segmentation and material recognition accurately.

Currently, no specific plugin is available to generate color palettes in BIM methodology directly. However, there are already some interesting scenarios where artificial intelligence is employed to assist designers in choosing the right colors for their projects. Some AI tools generate basic creative solutions. Some of them allow the colorization of black-and-white images, or they can shift the colors of pre-existing images. Other recent solutions enable these operations through typical AI prompts. Tools such as "Colormind," "Adobe Color," "Coolors," "Canva Color Palette Generator," "Huemint," and "Palette.fm" aid designers in generating color palettes. However, while they use AI techniques to various degrees, they are not exclusively AI-based. They cater to diverse design needs, from web design to interior decor, but are not directly integrated into BIM methodology. Instead, in Autodesk Revit, one of the most used BIM applications, plugins like "Veras" and "ArkoAI" are pioneering tools. Veras transforms 3D models into realistic visualizations in Revit. It uses user prompts to articulate color preferences, although final adjustments may be needed. "ArkoAI" enables AI-driven visualizations in Revit, guided by user directives and settings. Both plugins adeptly intertwine human preferences and AI within the color palette generation process, bridging creativity and technology.

Applying AI to color selection in BIM presents computational challenges, necessitating substantial resources and careful interpretation of AI-generated color schemes. Transparent interpretation is vital to align AI results with architectural visions effectively. Despite challenges, AI holds substantial potential to revolutionize color selection in BIM, provided these issues are addressed. While AI offers immense potential, it is essential to address computational and interpretative challenges to facilitate its seamless integration into BIM workflows.

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On the need of accurate device calibration in color vision deficiency computer assessment

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Abstract

Among the wide offer of Color Vision Deficiency (CVD) assessment tests, only a few are designed to be administered via digital display monitors and thus require accurate color calibration and profiling. On the one hand, using fully characterized and calibrated devices is desirable to reduce the error introduced by inter-device variability. However, the need for a calibrated device restricts the opportunities for users and institutions to perform pre-screenings, low-cost tests, and online/remote tests. Making tests more accessible and available to users might increase the awareness and understanding of CVDs and should help potential CVD observers, whose status might go unnoticed and undiagnosed for years. In this paper, we analyze data gathered using a simple online game (http://qolour.it) to determine whether it is possible to avoid controlled environments and protocols for CVD pre-screening purposes. In particular, we analyze the use of mobiles, tablets, and personal computers to perform CVD pre-screenings, comparing the results and performances obtained by a control group with the rest of the users.

Introduction

Qolour (*www.qolour.it*) is a web-based serious development aimed both at helping people obtain a pre-screening assessment of a possible color vision deficiency (CVD) and collecting big amounts of data inherent to color vision and color perception (Armellin, et al. 2022). It is currently under development, and as such many aspects of the game needs to be analyzed to prove its overall effectiveness, ranging from data collection to data analysis and to user experience. While, at its current version, it proved reliable in correctly identifying the color vision deficiencies of subjects in a control group, we also analyzed the data gathered since the first time Qolour wash published for free usage using statistical metrics that don't require a laboratory setting.

When the game starts, the player is presented with seven differently colored shapes arranged in a circular fashion, with another slightly bigger one in the center surrounded by an animated timer; the purpose of the game is to press, before the timer expires, on the outer shape with the same color as the central one. The central color, which will be referred to as the *target color*, is generated randomly inside the HSL space, and subsequently converted to RGB, with the Hue being completely random, Saturation bounded between 0.6 and 0.8 and Lightness fixed to 0.5; one of the outer colors is the same as the target color, while the remaining six are chosen as to lie on confusion lines corresponding to the three types of dichromats; the background color of each level changes and can randomly be achromatic (having the same Lightness of the target color) or colored (a pseudorandom color computed such that it has the opposite Hue of the target color plus or minus 10 degrees but the same Lightness and Saturation).

The game has been administered to a control group consisting of 8 color-deficient observers (CDOs) and 8 normal color observers (NCOs), each of which had been given a link and required to freely interact with the web interface and play as much times as they wanted, regardless of their physical location, time of day and device; the only constraints given were that they should not wear any glasses, with the exception of prescription ones, nor use any colored filters (both physical or digital), like the yellowish ones implemented by many smartphone OSs to prevent "blue light fatigue". Each of the control subjects has been categorized as a NCO or a CDO based on the results

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scored on combination of various tests administered in a supervised fashion and a controlled environment, the tests being the 38-plates Ishihara PIP Test (version printed in 2021), the digital version of the Farnsworth D-15 test, and the anomaloscope (model OT-II manufactured by Neitz Instruments)

Qolour proved effective in classifying each of the control subjects as either CDO or NCO, as well as correctly distinguishing the three protan/protanomalous observers from the five deutan/deuteranomalous. It’s worth noting that none of the subjects had been screened with tritanopia, being a rare condition often requiring specialized equipment to be correctly diagnosed such as, for example, anomaloscopes using Engelking-Trendelenburg or Pickford-Lakowski match rather than standard Rayleigh match (Pokorny, J; Collins, B; Howett, G; 1981).

Results

At the time of writing, Qolour has been played by 4 012 users from 94 different countries, totaling 6 452 games played and 117 692 total levels. Most of the devices used to access the website have been tablets and smartphones, the number of estimated unique devices being comprised between 800 and 1 900, which is just a rough estimate based on the collected user-agents.

Using the currently implemented metric (which slightly changed since the first release in Q2 of 2022), out of the 4 012 players, 3 660 have been classified as NCO whereas the remaining 352 as CDO, leading to a percentage of around 8.8% of CDOs among the whole population of players; Tab. 1 shows the actual numbers of players with their classification, players categorized as “deutan/protan” are the ones that make similar errors in both deutan and protan directions for which a clear distinction cannot be made having an high uncertainty, while the differentiation of anomalous trichromats from dichromats is not being carried out in the current version of Qolour.

<table>
<tr><th>Deficiency</th><th>Total players</th><th>% (total)</th><th></th></tr>
<tr><td>Normal</td><td>3 660</td><td>91.23 %</td><td>91.23 %</td></tr>
<tr><td>Protan</td><td>146</td><td>3.64 %</td><td rowspan="4">8.77 %
(all deficiencies)</td></tr>
<tr><td>Deutan/Protan</td><td>27</td><td>0.67 %</td></tr>
<tr><td>Deutan</td><td>174</td><td>4.34 %</td></tr>
<tr><td>Tritan</td><td>5</td><td>0.12 %</td></tr>
</table>

Tab. 1 – Estimate of the distribution of deficiencies among the players population of Qolour.

To simplify visualization, in the following plots target colors have been grouped in larger classes derived from the sampling of all the target colors shown to the players from 8 bit to 4 bit per channel (reducing the possible colors to 4096 representative classes); these classes have been used to compute both the percentage of correct answers for each color class (Fig. 1) as well as the variance of the answers (Fig. 3).

Fig. 1 shows the percentage (along the radius, ranging from 0% to 100%) of correct answers given by all the non-deficient observers for each color class hue (in degrees along the circumference). It can be noted that all the target colors having a hue ranging from red to green were more easily correctly identified by the players (with a success rate above 90% for most of the hues), whereas a higher error rate occurred when challenged in correctly identifying light blue to magenta hues, with an error rate getting as high as 40%.
This tendency needs to be further analyzed, since it appearead with almost every individual labeled as NCO, leading to higher error rates along the tritan confusion lines with respect to CDOs. Given

this anomaly and the unavailability of tritan control subjects, as of now a user is flagged as tritan only if all the errors committed fell onto tritan confusion lines in the first 20 levels, the easier ones where NCOs doesn't seem to commit as much errors as in further levels.

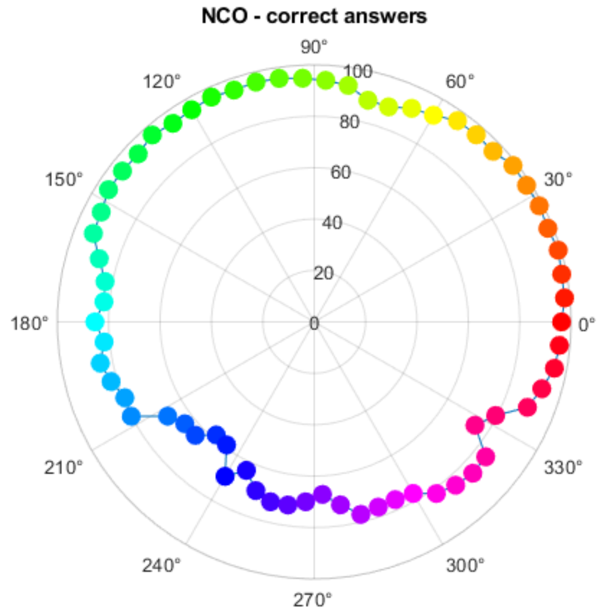

Fig. 1 – Percentage of correct answers by hue given by normal color observers between level 10 and 39.

Later the variance of the answers given by both the CDOs and the NCOs has been evaluated; a choice has been made to evaluate only the variance among the hues for two main reasons:

- Each level of the game presents the user with colors with roughly the same brightness and saturation, mainly the hue changes
- Visualization of variances in 3D spaces (such as RGB or xyY) is not trivial

The variance among the hues has been computed using the following algorithm:

```
for each level l {
      for each target color tc {
            for each background bg {
                  compute σ^2_h as the variance of the n h_j
                  hues of the colors chosen by the players.
            }
      compute σ^2_tc as the average of all the m σ^2_h,
      weighted by the numerosity q_h of the samples.
      }
}
```

In this way, the variances are computed only among the users who have been shown the same target (as to avoid comparing different stimuli between them), with the same background color (since different backgrounds may introduce simultaneous contrast) and at the same level (since different levels comes with different difficulties derived from a varying distance between the target color and all the possible colors shown to the player). The var_h variances have been computed as shown in Eq. 1, while the average variance for each target color has been computed using Eq. 2; from Eq. 1 can be seen that the resulting variance is always normalized between 0 and 1, where 1 represents the distance between two colors having their hues 180° apart.

$$\bar{h} = \operatorname{arctan2}\left(\frac{1}{n}\sum_{j=1}^{n}\sin\left(h_j\right),\ \frac{1}{n}\sum_{j=1}^{n}\cos\left(h_j\right)\right)$$
$$\sigma_h^2 = \frac{1}{n}\sum_{j=1}^{n}\left(\frac{1}{\pi}\operatorname{arctan2}\left(\sin\left(\bar{h}-h_j\right),\ \cos\left(\bar{h}-h_j\right)\right)\right)^2$$

Eq. 1

$$\sigma_{tc}^2 = \frac{1}{\sum_{h=1}^{m} q_h}\sum_{h=1}^{m}\sigma_h^2 \cdot q_h$$

Eq. 2

The variances have been evaluated only between level 10 and level 39, the lower limit being chosen because levels prior to 10 are purposefully easy to show the user how to interact with the game and are not meant for actual data collection nor are taken into consideration for evaluating the player's color perception, the upper limit being chosen because level 39 coincide with the 3rd quartile of all the observations, as can be seen in Fig. 2.

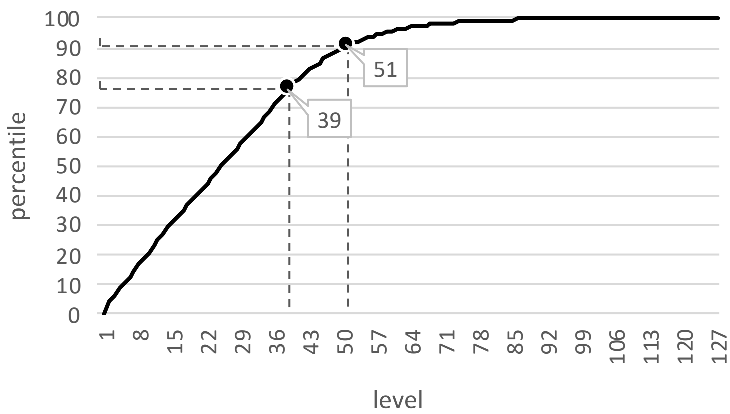

Fig. 2 – 75% of all the observations lies between level 1 and 39, with just 25% of all the observations being made in higher levels. This indicates how most of the players struggles to get past the first 40 levels, with levels above 51 comprising only 10% of all the observations.

The plots in Fig. 3 show the normalized variances for each target color class (computed by sampling all the possible target colors with 4 bits per channel), the hues are shown on the circumference and the variances on the radius axis. For the sake of readability only some representative levels and variances up to 99th percentile are shown in the following plots, instead a synthetic report for all the levels is shown in Tab. 2.

	NCOs			**CDOs**		
Level	**Mean σ²**	**Mean hue variability**	**Numerosity**	**Mean σ²**	**Mean hue variability**	**Numerosity**
10-14	$2.71\pi^2 \cdot 10^{-5}$	± 0.94 °	9600	$1.05\pi^2 \cdot 10^{-3}$	± 5.83 °	2763
15-19	$5.50\pi^2 \cdot 10^{-5}$	± 1.33 °	9431	$7.42\pi^2 \cdot 10^{-4}$	± 4.90 °	1917
20-24	$8.99\pi^2 \cdot 10^{-5}$	± 1.71 °	9205	$5.78\pi^2 \cdot 10^{-4}$	± 4.33 °	1584
25-29	$8.94\pi^2 \cdot 10^{-5}$	± 1.70 °	9771	$5.36\pi^2 \cdot 10^{-4}$	± 4.17 °	1326
30-34	$1.46\pi^2 \cdot 10^{-4}$	± 2.17 °	9384	$2.47\pi^2 \cdot 10^{-4}$	± 2.83 °	1121
35-39	$3.63\pi^2 \cdot 10^{-4}$	± 3.43 °	10928	$3.32\pi^2 \cdot 10^{-4}$	± 3.28 °	717

Tab. 2 – Average variances and hue variability in each group of levels, divided between NCOs and CDOs, with the numerosity referring to the number of times the corresponding levels have been played.

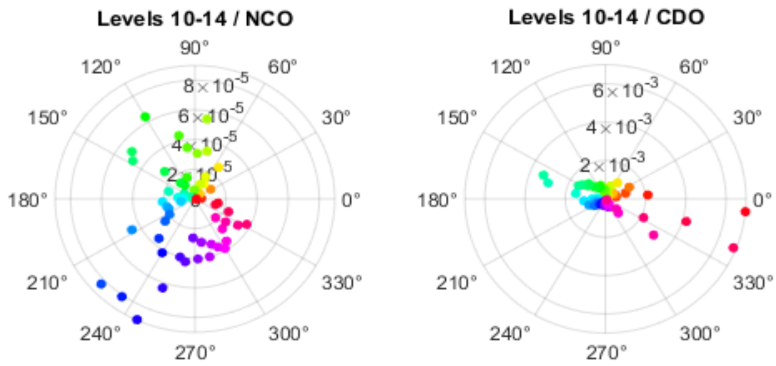

Fig. 3-a – Average variances among the levels from 10 to 14.

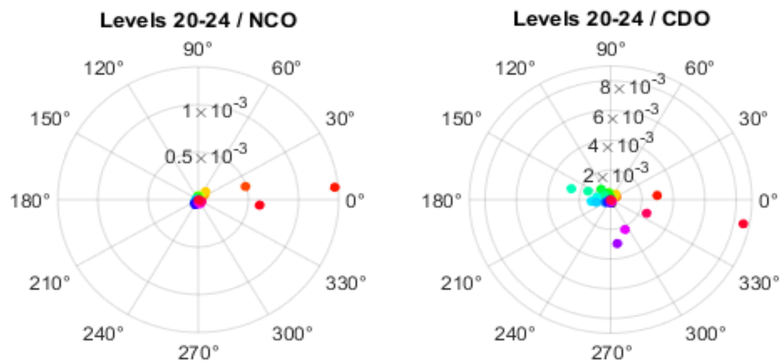

Fig. 3-b – Average variances among the levels from 20 to 24.

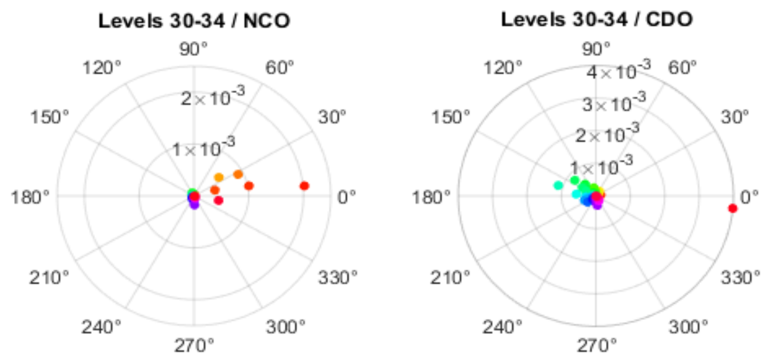

Fig. 3-c – Average variances among the levels from 30 to 34.

Discussion

Even though results obtained among the control group seems to show a certain degree of reliability in guessing the deficiencies of the subjects in the control group, the numerosity of the group is relatively low (being composed of only 16 subjects), it is thereby mandatory to include further analysis on the gathered data, which we included in the "Results" section.

The incidence of CDOs in the players population shown in Tab. 1 is close to the global incidence, which is of around 8.8% in males and 0.4% in females (Birch, 2012; Hunt and Carvalho, 2016). With respect to the specific deficiencies, the protan/protanomalous subjects appears in a higher incidence than in the actual global population (Padgham and Saunders ,1975); this can anyway be a result of the non-optimal segmentation carried out by Qolour, which has been tuned on an overall small sample of control subjects, as discussed above, showing thus room for improvement once a control set with a greater number of subjects will be tested.

The percentage of correct answers given by NCOs for each hue shown in Fig. 1 shows two different behaviors based on the considered target colors' hue, for the blue-to-magenta being the most difficult to correctly identify, and the green-to-red being the easiest. The rationale behind the analysis of the correct answers given by NCOs, and NCOs only, is such that correctly identified NCOs should show a high percentage of correct answers; this approach still relies on the segmentation of the data between estimated player's deficiencies which, as stated, is not optimal.

The analysis of the variance among the chosen hues shows an overall low variance for both NCOs and CDOs, indicating a high level of consistency between the gathered data even using uncalibrated devices in uncontrolled environments. As the level increases, the colors shown to the player get less and less different between one another, effectively reducing the intra-level variance of displayed colors, while increasing the difficulty; the fact that variances from the lower to the higher levels remains roughly the same and of the same magnitude (with few exceptions), as can be seen in Tab. 2 seems to indicate that, regardless of the specific difficulty of the levels, the majority of the players are prone to give the same answers when presented with the same target and background colors. This trend is also confirmed when compared with the plot in Fig. 2 showing correct answers against hues for the NCOs, here we can see from the plots in Fig. 3 that variance remains low even for the blue-to-magenta hues, where NCOs seems to commit multiple errors; the same applies for CDOs observers that shows a low variance even though their error rates is significantly higher than that of NCOs, especially in levels above 20. The maximum variance is seen in the first 5 levels played by the CDOs, showing ±5.83 degrees in hue, which is definitely noticeable even if small, while staying under ±3 degrees for the NCOs with the exception of the last 5 levels considered.

Conclusions

The results of the analysis on the data gathered in the past several months show a certain consistency, while also outlining some issues. The low overall variance in hue among the answers given by the players presented with similar visual stimuli suggests that on average users respond in similar ways regardless of the device they are using or the environment in which they are playing, which pose the basis for a visual test that can be rendered accessible to the whole population and enables data collection for research purposes on a potentially worldwide scale.

In testing against the control group, Qolour proved effective in correctly discriminating subjects with color deficiency from those without; as the number of players increased over the months, the overall incidence of deficient subjects settled to a value close to that of the estimated global average.

Some issues emerged and remain open, for example the difficulty in discriminating tritan observers from normal observers, given the high error rates both in the direction of the tritan confusion lines as well as with blue to magenta target colors, analyzing data collected from thousands of session enabled the discovery of such critical issues which could've been not so evident in a controlled laboratory setting with a test population of orders of magnitude smaller.

It is clear that an app cannot be an alternative to a professional diagnosis carried out in a controlled setting, but the development of freely accessible apps and games might help in rapidly carrying out pre-screenings that could motivate individuals to seek for a professional opinion on a condition they might've not even known, as well as raising awareness in the general public on the existence of color vision defects and their meaning. The tradeoff between accuracy and accessibility should not be overlooked, especially since most of the most common and studied tests need particular and expensive equipment.

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3. Color and Lighting

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Color design and glazing systems in the architecture of Algerian mosque

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Abstract
This study investigates the color design of the glazing systems as an important decoration elements in the architectural space of the mosque. The research methodology was conducted by the combination of descriptive analysis and simulation methods. The first step was the select of thirty mosques located in six Algerian cities. The second step was the collect of data by visiting the selected mosques for in-situ observation and photography the opening elements. The collected data was analysed using descriptive analysis in the aim to classify the adopted daylighting systems, and using numerical simulation to extract the dominant color used for the glazing. The final step was the application of the multiple correspondence analysis in order to measure the degree of similarity between the studied mosques. This leads to distinguish three ways of the use of colored glazing in the space: (i) the add of colored effect that promotes the concentration of the users on the religious activities. (ii) the adoption of spiritual elements from the external environment by applying their color to the glazing. (iii) the use of the architectonic decoration elements for the shapes of the glazing. The findings of this research can be integrated as a guidelines to architects for their mosque design about the color choices of the daylighting and glazing systems adapted to the local cultures and to the luminous characteristics of the site.

Keywords: Islamic decoration, Algerian Mosque, Color design, Glazing system, Chromatic composition.

1. Introduction

One significant aspect of the Islamic architecture is the spirituality given to the decoration of the space by the add of semantic loads to the building components (Petruccioli & Pirani, 2013; Abdollahi, 2021). This design practices are interpreted by the researches as a visual demonstration of the Islamic religious believes (Kahera, 2002). The mosque is by far a particular example of the manifest of the aesthetic principles of the Islamic decoration (Rashid, 2020). Over the history, this sacred building has been considered as the most ingenious invention on the Islamic world because of its ability to encompass several Islamic activities and practices that can be religious, educational and social (Ouedraogo, 2007). Since the beginning of the current century, a very large number of mosques have been built throughout the world (Khan, 1990). The construction of the mosque is considered to be a charitable act and was generally accompanied by the creation of a pious foundation that covered all steps of the buiding design and construction (Holod et al., 1997). In Algeria, the construction of mosques in the current era is in full evolution by the use of new methods and design technologies as well as the adaptation of the building to the contemporary architecture requirements (El-Akkad, 2013). Of all visual elements, light and color are two important visual elements used by the architects for the design of mosques from the earliest times by encompassing technical mastery and symbolic meaning (Dittelbach & Sebestyén, 2017). The issue of the spiritual dimension of the daylighting systems and the color design in the architectural space of the mosques is the topic that had previously gained prominence within the scientific community. (Johnston, 2015). In this regard, this research aims to analyse the color of the daylighting systems in Algerian mosques in order to understand how these architectural elements were developed, and how they contributed to the design of the building. It discusses the changes in aesthetics by comparing examples from several Algerian cities.

2. Literature review

2.1. Light and color in the religious space

In addition to calligraphy, arabesque and architectonic elements, light and color are two basic decoration and aesthetic elements affecting the spatial value and the human perception of the space of the mosque (Nejad et al., 2016). Through history, daylight has been not only used to illuminate the interior space of the mosque but also as a mystical design tool. (Michel, 1995). The importance of daylight is also evident in the enormous attention given to the decoration of the window from the earliest times which has been used to give weightlessness and ephemerality to the space (Siniscalco et al., 2022). Since that, architects used daylight as an experiential element of their design. Moreover, natural light influences other aspects of the space such as color, texture, etc. Color is considered as an irreplaceable companion of light, and an important key element in the architecture of the mosque (Avaznejad & Sheibani, 2021). Over the centuries, color has been converted to symbols of internal feelings of social and personality states (Sadeghi Habibabad et al., 2022). The manifest of color in the material forms is regarded as its ability in the mundane world. (Riggs, 2008).

2.2. Colored glazing system and the space decoration

Colored glazing systems are considered as a powerful tool to add motility and life to the decoration of the space and therefore to express the history and the evolution of the place (Chen et al., 2017). Early, colored glass has been used in the mosque primarily to connect the space to nature. Later, it embodied meaning by the use of stained glass in the aim to achieve colored effects on the interior surfaces. Nowadays, colored and stained glazing became more common when distinct regional trends emerged (Phillips, 2012). Nowadays, the chromatic composition accumulated the most scientific knowledge and preference. It is considered as a critical factor affecting the observers' aesthetic judgments on the architectural space. Although attempts to analyse chromatic composition shed light on artistic strategies contributing to aesthetics (Nakauchi et al., 2022).

2.3. The perception of the chromatic composition

The perception of the chromatic composition is influenced by a range of factors such as the dominant color, the organisation way and also the simultaneous contrast depending on the relative luminance of their context (Cesar, 2018). The color's meanings of the chromatic composition of the daylighting systems in the space of the mosque are various: (i) Yellow color symbolizes the warmth of the sunlight, the life, the hope, wisdom and the knowledge. (ii) Green color is a middle and balanced color in the spectrum; it evokes a sense of prosperity, the symbol of other life, growth, and eternity. It is also the color of patience, tolerance, and sustainability. (iii) Blue color is a clear and bright color; a symbol of spirituality and faith, a sacred color in the Islamic culture, because it is the color of sky, pure souls, and angles. (iv) White color indicates indiscrimination, perfection, pureness, illumination, innocence, and sacredness (Lam & Ripman, 1977).

3. Research Methodology

The research methodology was developed by the combination of descriptive analysis and simulation methods. This multidisciplinary approach was adopted as result of the complexity of the studied phenomenon. The objective is to identify sensory drivers of the phenomena in order understand its design process and the resulting effect on the space. Descriptive analysis has been used to describe the nature and the magnitude of the sensory characteristics of the studied phenomenon when numerical simulation has been used to mesure its quantitative properties (Hootman, 1992; Kemp et al., 2018). The in-situ observation and the photography have been used to collect data. The analysis process includes numerical simulation and the multiple correspondence analysis in order to measure the similarity between the whole mosques.This allows to understand and identify sensory drivers of the phenomena in order to optimise its design process.

3.1. The case study

This step was carried out by the choose of a representative corpus of thirty mosques located in six Algerian cities: Annaba, Bejaia, Biskra, Guelma, Setif and Skikda. The exploration of the climate patterns of each location has been conducted in order to understand the colorimetric characteristics of the luminous environment mainly the sky the sunlight properties.

Table. 1 - The selected mosques

N°	Mosque	Name on Arabic	City	Coordinates
01	Arkam Ibn Abu Sofiane	مسجد ارقم ابن أبي سفيان	Annaba	36.8973 N, 7.7380 E
02	El-Nour	مسجد النور	Annaba	36.8932 N, 7.7411 E
03	El-Ferdous	مسجد الفردوس	Annaba	36.9241 N, 7.7583 E
04	Okba Ibn nafea	مسجد عقبة ابن نافع	Annaba	36.9001 N, 7.7440 E
05	Quba	مسجد القبة	Annaba	36.9192 N, 7.7523 E
06	El-Chouhada	مسجد الشهداء	Bejaia	36.7145 N, 5.0400 E
07	Bilel Ibn Rabah	مسجد بلال ابن رباح	Bejaia	36.7472 N, 5.0350 E
08	El-kaother	مسجد الكوثر	Bejaia	36.7518 N, 5.0532 E
09	Iheddaden	مسجد احدادن	Bejaia	36.7418 N, 5.0442 E
10	El-Ferdaous	مسجد الفردوس	Bejaia	36.7598 N, 5.0771 E
11	Al-Taouba	مسجد التوبة	Biskra	34.8416 N, 5.7099 E
12	Al-Rahman	مسجد الرحمان	Biskra	34.8551 N, 5.7216 E
13	Al-Salam	مسجد السلام	Biskra	34.8473 N, 5.7025 E
14	Al-Souna	مسجد السنة	Biskra	34.8499 N, 5.7095 E
15	Sidi-Sohbi	مسجد سيدي الصحبي	Biskra	34.8471 N, 5.7318 E
16	Abderrahmane ben Badis	مسجد عبد الرحمان ابن باديس	Guelma	36.4660 N, 7.4295 E
17	Bilal Ibn rabah	مسجد بلال ابن رباح	Guelma	36.4529 N, 7.4238 E
18	El-Mirage	مسجد المعراج	Guelma	36.4708 N, 7.4380 E
19	El-Quods	مسجد القدس	Guelma	36.4611 N, 7.4285 E
20	Moussa Ibn noussir	مسجد موسى ابن النصير	Guelma	36.4599 N, 7.4156 E
21	Imam Al-Ghazali	مسجد الامام الغزالي	Setif	36.2901 N, 5.4115 E
22	Guedjel	مسجد قجال	Setif	36.0565 N, 5.5608 E
23	El Houda	مسجد الهدى	Setif	36.2109 N, 5.4282 E
24	El- Furqan	مسجد الفرقان	Setif	36.2097 N, 5.4065 E
25	Imam Ali Ibn Abi Talib	مسجد الامام علي بن أب طالب	Setif	36.1962 N, 5.4018 E
26	Awal Novembre	مسجد أول نوفمبر	Skikda	36.8654 N, 6.9247 E
27	Al-Ansar	مسجد الانصار	Skikda	36.8781 N, 6.8901 E
28	Ibn El-Djarrah	مسجد ابن الجراح	Skikda	36.8774 N, 6.9322 E
29	Omar Ibn el khattab	مسجد عمر ابن الخطاب	Skikda	36.8714 N, 6.9135 E
30	Al-Rahmane	مسجد الرحمان	Skikda	36.8575 N, 6.9243 E

3.2. Data collection and analysis

The collect of data has been carried out by visiting the mosques during the prayer time in order to observe the luminous characteristics of the space and also to photography the daylighting elements including the glazing systems. The analytical process was conducted by numerical simulation using specific software in order to extract the color for the glazing system. The simulation results have been submitted to a categorisation in the aim to explore the degree of similarity between the studied mosques. IBM SPSS Statistics 26® program has been used to insert data in table made up of rows corresponding to the mosques, and columns corresponding to the variables.

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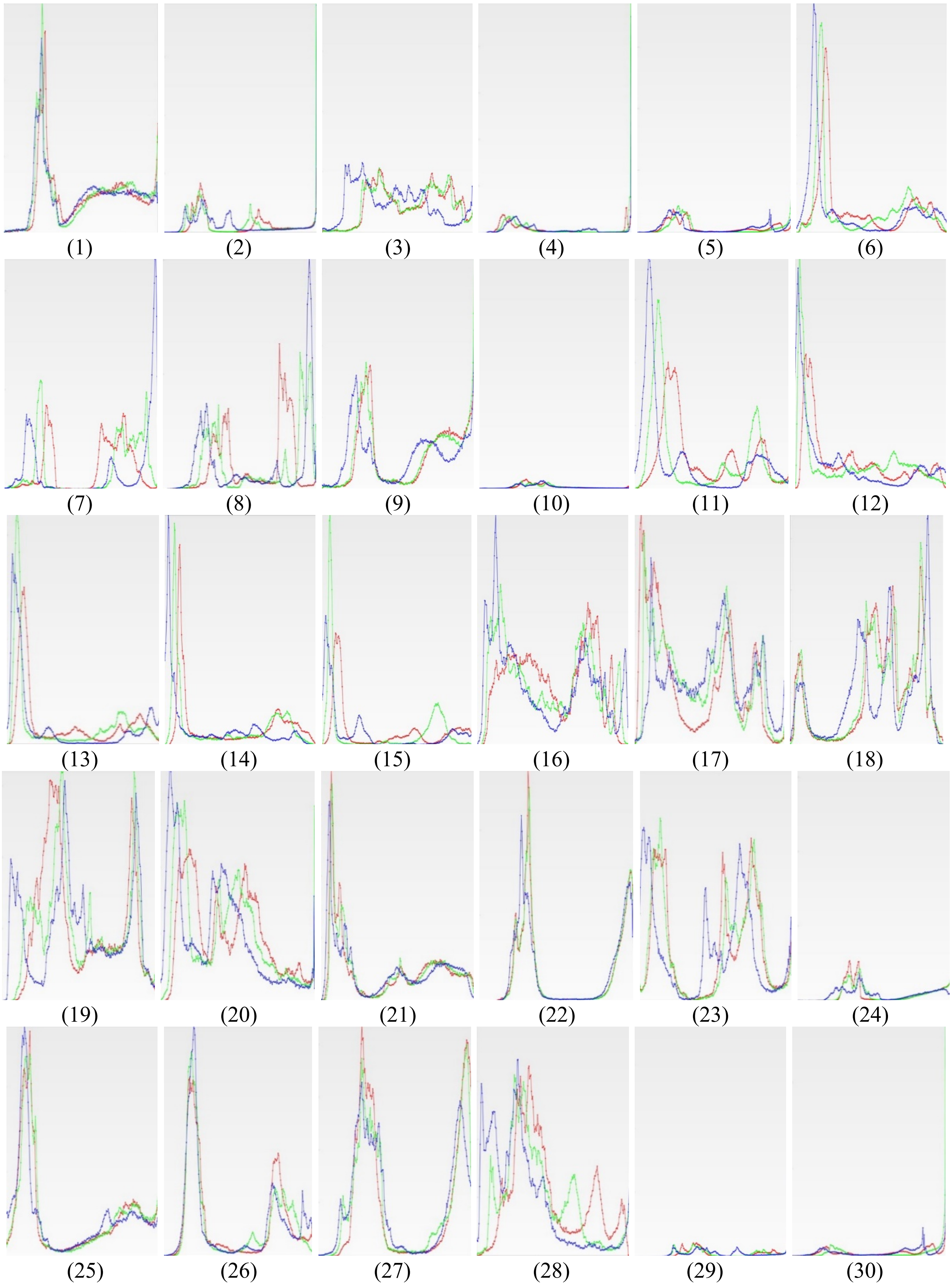

Fig. 1 - RGB diagrams corresponding to the windows photography

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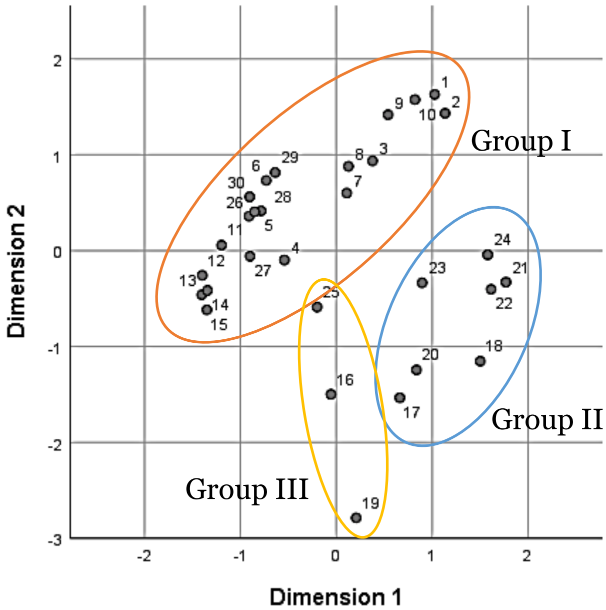

Fig. 2 - Graph of scatter plot. (Source : Output IBM SPSS Statistics 26®)

4. Results & discussions

The results demonstrates the direct relationship between the choice of the designer about the glazing system and the characteristics of the luminous environment of the geographic location. A reading of the graph on (Fig. 2) shows that there are three groups of mosques corresponding to three strategies of color design:

The first group includes the largest number of mosques; its main characteristic is the use of multiple color for the glazing precisely Orange and Brown color group including Yellow, Green, Blue and white. The color organisation is based on geometric and orthogonal composition. The adopted color are fairly distributed following hierarchical way; color placed from bottom to top, peripheral way; color situated on the perimeter, and central way; color are repeated following a radiant frame. In addition to the colored effect given to the space, the opacity of the glazing promotes the relationship between the user's activities and the space.

The second group also includes a significant number of mosques. However, it is characterized by the use of a single color for the glazing mainly consisting of either Cyan-Blue or Green-Cyan. The adopted glazing is clear and made by repetition of rectangular shape covering the entire surfaces of the opening element. In addition to their spiritual meanings in Islamic decoration, the employed color consolidate the visual continuity between the interior space and the external environment; the blue accentuates the color of the sky and draws the vision upward, while the green enhances the color of the surrounding vegetal environment.

The third group includes a reduced number of mosques. It is characterized by the use of white and translucide glazing filling the entire surface of a simple geometric shape. The specificity of this group is the reflection of the exterior architectonic elements of the facade on the glazing surface that modify its shape of the window and add a visual effect on the interior space. This allows the glazing to reflect the color of the sun's rays, thus reminding the user of the time of day without visual contact with the external environment.

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Fig. 1 - The opening elements of the studied mosques: on the top-the first group-from left to right; hierarchical, peripheral, centric. Bottom left; the second group. Bottom right, the third group.

Conclusions

This study is an application of the acquired scientific knowledge in the fields of lighting and glazing systems on the sacred space of the mosque. The main conclusion is that the choice of the color and its distribution on the window is conducted by design strategies that differ from one region to another according to three main factors: (i) the characteristics of the light environment of the site. (ii) the culture and the history of the population. (iii) the activities and occupation time on the space. The results can be used as recommendations that can be helpful to the architects during their design of mosques precisely in the choose of the color and chromatic composition of the glazing systems according to the luminous and social caracteristics of the location. The need for the extension of the case study and the add of other aspects especially the acoustic is very important in order to make it possible to build a global design method and an appropriate architecture for the Islamic community and meeting the today's requirements of the contemporary trends.

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Variations in photopic and melanopic total reflectance of interior colors under different light sources: Which implications for lighting design?

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Abstract
Surfaces' optical characteristics contribute to determining the spatial and spectral distribution of light within spaces, in turn affecting visual and non-visual responses to light and the general room's appraisal. Photopic and melanopic reflectance values, expressing surfaces' potential in reflecting the parts of the radiation able to stimulate human visual and circadian systems respectively, help designers in choosing colors and materials for indoor applications. These values are reported in technical sheets or in online databases referring to the CIE D65 illuminant. However, since both photopic and melanopic total reflectance depend not only on the material but also on the spectral irradiance, the aforesaid values may not be valid anymore under spectra other than D65. Here, this topic is deepened through a systematic analysis: the total photopic and melanopic reflectance values of 195 color samples selected from the Natural Colour System are calculated considering 18 LED spectra grouped in warm, intermediate, and cool, and 4 CIE standard daylight illuminants besides D65. Then, for each sample, the reflectance values (both photopic and melanopic) under each light source are compared against the corresponding ones under D65 obtaining percentage differences. Results show that, for each sample, reflectance values under sources belonging to the same group are very similar to each other, and that those under all daylight spectra are almost equal to the corresponding values under D65. Regarding electric light sources, low percentage differences occur under cool LED, whereas high ones under warm LED. These results are valid for both photopic and melanopic reflectance. Also, color attributes are crucial. Specifically, hue defines the amplitude of percentage difference ranges and if they are positive or negative, with different effects on photopic and melanopic reflectance. On the contrary, chromaticness affects photopic and melanopic reflectance in the same way: the higher the chromaticness, the higher the percentage difference.

Keywords: integrative lighting, colors' optical characteristics, photopic reflectance, melanopic reflectance, reflectance variations under different light sources

Introduction

About two decades ago, intrinsically photosensitive retinal ganglion cells (ipRGCs) were identified in the mammalian eye. Since then, interest in the so-called non-image-forming (NIF) effects of light has increased. NIF effects of light include, for example, the influence of light on people's alertness and sleepiness state, working performances, mood, and general well-being. Indeed, the ipRGCs convert light stimuli into neuronal signals then transmitted to the suprachiasmatic nucleus (SCN) which, in turn, regulates hormones secretion (e.g., cortisol and melatonin) and is responsible for the entrainment of many human physiological and behavioral rhythms known as circadian rhythms (Berson, Dunn and Takao, 2002). Recent research underlined that the disruption of circadian rhythms brings serious diseases (Fishbein, Knutson and Zee, 2021). Based on this awareness, the role of light in human life has been rethought. This is testified by the position statement on non-visual effects of light, *Recommending proper light at the proper time*, published by the International Commission on Illumination (CIE), where the integrative lighting concept is defined as "lighting integrating both visual and non-visual effects, and producing physiological and/or psychological benefits upon humans" (CIE, 2019). Also, the rise of voluntary building certification protocols, such as the WELL Building Standard (WELL Building Standard, 2023), recognizing the role of light in creating healthy buildings, remarks that designers are now required to manage both the visual and circadian effects of light in their projects.

In this respect, the choice of colors for inner surfaces is one of the main aspects in the building design process that can have an impact on both visual and circadian effects (Bellia and Fragliasso, 2021). Indeed, each opaque surface is a secondary light source that reflects the radiation incident on it, contributing to determining the quantity, spatial and spectral distribution of the light in the space. Previous studies have demonstrated that different colors of inner walls lead to different ipRGC's stimulation (Bellia, Pedace and Fragliasso, 2017) and illuminance values on working planes (Bellia *et al.*, 2022) even under the same light source. Other studies found that, in general, highly reflective surfaces are more prone to guarantee sufficient ipRGCs' stimulation and visual requirements' accomplishment (Dai *et al.*, 2018; Acosta *et al.*, 2019).

To help designers in choosing colors and materials for indoor applications accounting for their overall impact on visual and circadian responses, melanopic reflectance has been proposed as a new parameter in addition to the photopic one. Indeed, this last parameter expresses surfaces' potential in reflecting the part of the incident light that stimulates human visual system. Similarly, melanopic reflectance, calculated using the ipRGCs' action spectrum s(λ) in place of the spectral sensitivity for photopic vision V(λ), expresses the potential of surfaces in reflecting the part of the incident radiation able to stimulate the circadian system. Designers can easily find materials' photopic and melanopic reflectance values calculated under the CIE D65 illuminant in technical sheets or in online databases such as the Spectral material database (Spectral material database, 2023). Nevertheless, both melanopic and photopic total reflectance values depend not only on the spectral reflectance of a material, but also on the spectrum of the incident radiation, hence values under D65 may not be valid anymore under different light sources.

To deepen this topic, in this study, a systematic analysis is carried out on 195 color samples selected from the Natural Colour System (NCS). Starting from measured spectral reflectance, colors' total photopic and melanopic reflectance values are calculated considering 23 spectra, i.e., the CIE D65 illuminant, 18 LEDs sources grouped in warm, intermediate, and cool and 4 standard CIE daylight illuminants other than D65. Values are compared against those calculated under D65 to obtain percentage differences. The higher the percentage difference, the greater the variation of color's reflectance under light sources other than D65.

Method

A systematic analysis is performed on 195 samples choosen in the Natural Colour System (Natural Colour System, 2023). The selected nuances are all those characterized by blackness equal to 5%, 30%, and 60% for the four unique hues (Y, R, B, and G) and to hues obtained by combining 30% and 70% of the two unique colors limiting each quarter of the color circle (Y30R, Y70R, R30B, R70B, B30G, B70G, G30Y, and G70Y).

The Konica Minolta CM-2600d spectrophotometer is used to measure the spectral reflectance of each "i^{th}" sample ($\rho_i(\lambda)$) in the range 360 nm – 740 nm with a 10 nm step. Then, for each sample, spectral reflectance with 1 nm step is obtained through linear interpolation. Hence, for each sample, the total photopic ($\rho^j_{ph,i}$) and melanopic ($\rho^j_{mel,i}$) reflectance values are calculated considering "j^{th}" electric light and daylight spectra. In particular, six warm LEDs with CCTs ranging from 2000 K to 3000 K (Group A), six intermediate LEDs with CCT equal to 4000 K (Group B), and six cool LEDs with CCTs ranging from 5700 K to 6500 K (Group C) are chosen among LEDs available on the market. In addition, the CIE D55, D60, D65, D70, D75 daylight illuminants (Group D) are also selected being representative of real daylight conditions (Bellia *et al.*, 2020).

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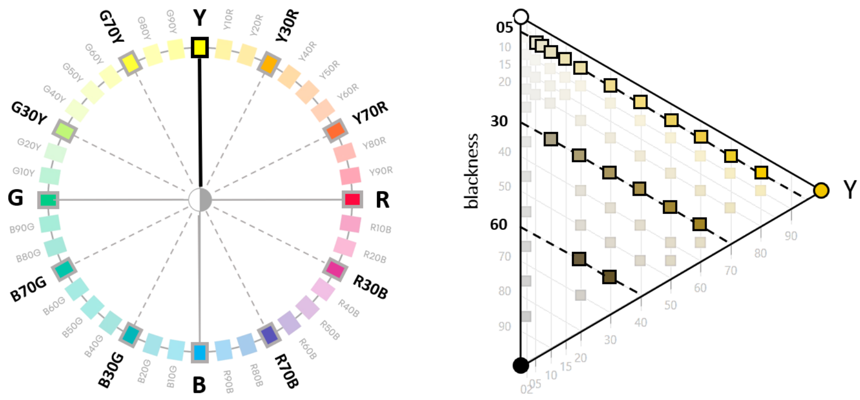

Fig. 1 – Selection of nuances belonging to the Y hue.

Calculations are performed according to Equation 1 and Equation 2:

$$\rho_{ph,i}^{j}\,[\%] = \frac{\int SPD^{j}(\lambda) \cdot V(\lambda) \cdot \rho_i(\lambda)\, d\lambda}{\int SPD^{j}(\lambda) \cdot V(\lambda)\, d\lambda} \qquad \text{Equation 1}$$

$$\rho_{mel,i}^{j}\,[\%] = \frac{\int SPD^{j}(\lambda) \cdot s(\lambda) \cdot \rho_i(\lambda)\, d\lambda}{\int SPD^{j}(\lambda) \cdot s(\lambda)\, d\lambda} \qquad \text{Equation 2}$$

where, SPD(λ) is alternatively the spectral power distribution of each of the 23 sources (see Fig. 2), V(λ) is the spectral response curve for photopic vision, and s(λ) is the ipRGCs' action spectrum.

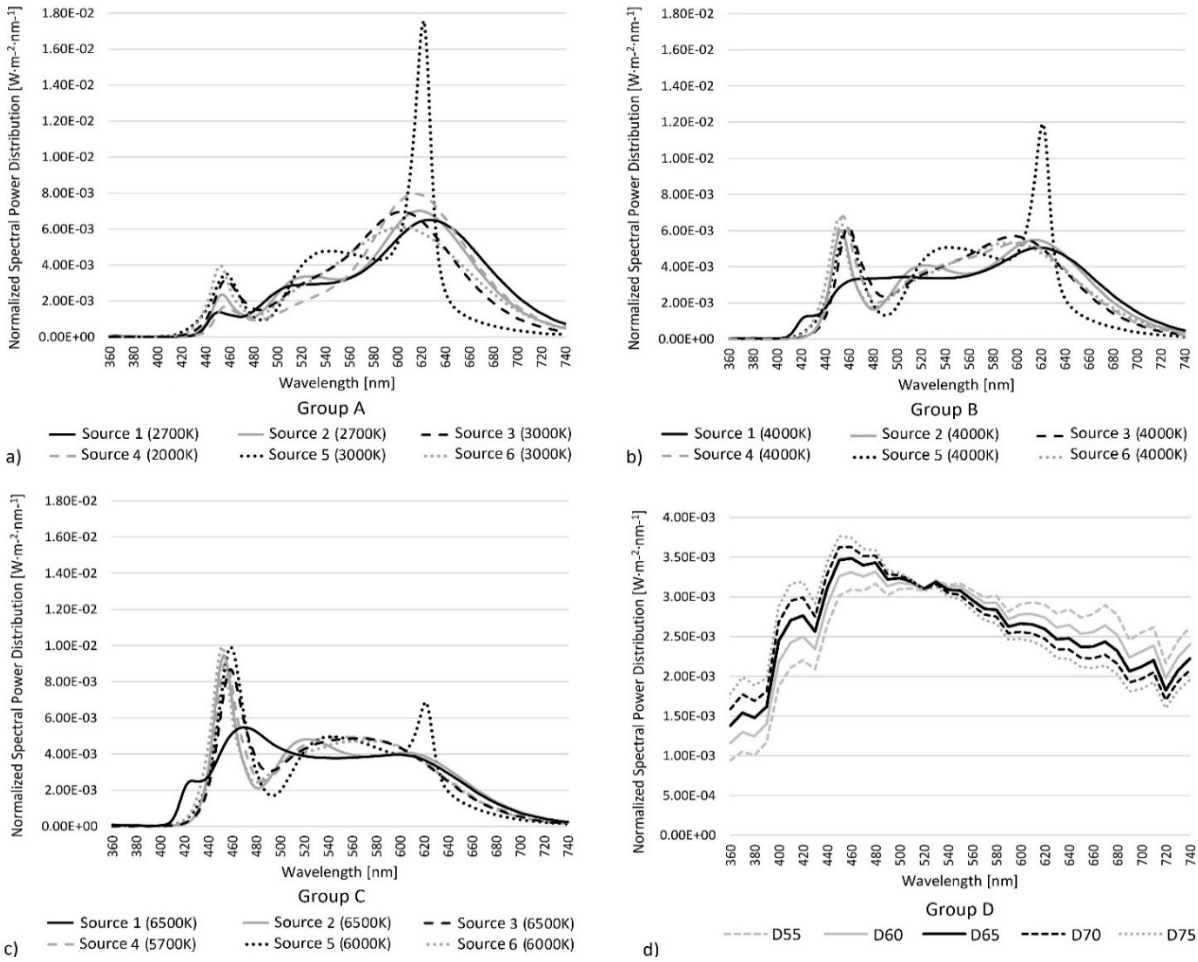

Fig. 2 - Warm (a), intermediate (b), cool (c) LED sources, and CIE daylight illuminants (d); sources' CCTs are reported in brackets.

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The integration is carried out in the range 360 nm – 740 nm.

Then, for each sample, the obtained "j" total photopic and melanopic reflectance values are grouped according to the sources' groups (A, B, C, and D). Hence, within each group, the average total photopic ($\rho_{ph,i}^{av}$) and melanopic ($\rho_{mel,i}^{av}$) reflectance values and the corresponding standard deviations ($\sigma_{ph,i}^{av}$ and $\sigma_{mel,i}^{av}$) are calculated.

Finally, for each sample, the total photopic ($\rho_{ph,i}^{D65}$) and melanopic ($\rho_{mel,i}^{D65}$) reflectance values calculated under the CIE D65 illuminant are considered as a reference. Indeed, the variations of the total photopic ($\Delta_{ph,i}$) and melanopic ($\Delta_{mel,i}$) reflectance values under light sources different from D65 are evaluated by means of Equation 3 and Equation 4 respectively:

$$\Delta_{ph,i}\ [\%] = \frac{\rho_{ph,i}^{av} - \rho_{ph,i}^{D65}}{\rho_{ph,i}^{D65}} \cdot 100 \qquad \text{Equation 3}$$

$$\Delta_{mel,i}\ [\%] = \frac{\rho_{mel,i}^{av} - \rho_{mel,i}^{D65}}{\rho_{mel,i}^{D65}} \cdot 100 \qquad \text{Equation 4}$$

where $\rho_{ph,i}^{av}$ and $\rho_{mel,i}^{av}$ are alternatively the average total photopic and melanopic reflectance values calculated for each sample within the A, B, C, and D groups.

Results

This section mainly analyses the variations of samples' total photopic and melanopic reflectance values calculated under light sources different from CIE D65 illuminant, highlighting the influence of colors' attributes (hue, chromaticness, and blackness) on these variations. However, some considerations about samples' total photopic and melanopic reflectance values under D65 illuminant are also reported for completeness. By way of example, Fig. 3 shows data relative to the nuances of hues belonging to the first quarter of the color circle.

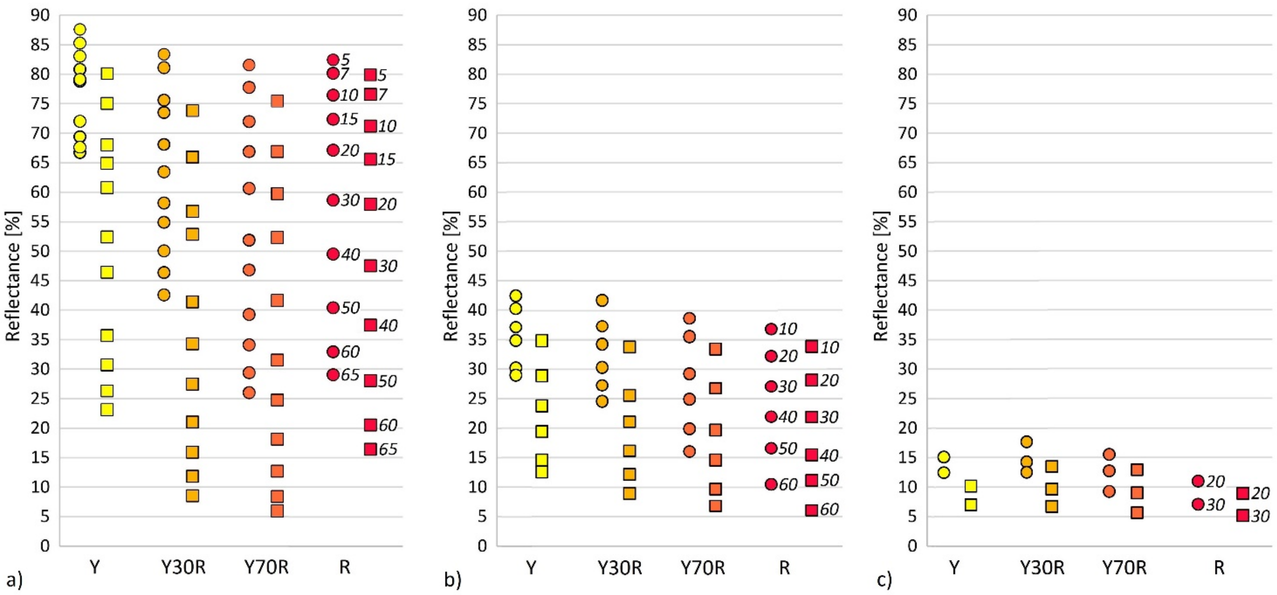

Fig. 3 - Photopic (circles) and melanopic (squares) reflectance values under the CIE D65 illuminant of nuances belonging to the Y, Y30R, Y70R, and R hues (by way of example, the chromaticness of the nuances of R hue are reported in italic); data are grouped for blackness equal to 5% (a), 30% (b), and 60% (c).

Results about samples' photopic and melanopic reflectance values calculated under the warm (Group A), intermediate (Group B), and cool (Group C) LED sources, and daylight illuminants (group D), are discussed in the following. First, it is found that, for each sample, standard deviations

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within each group are always small, for both photopic and melanopic reflectance. In particular, as regards photopic reflectance, the highest standard deviation is equal to 2.57 % (occurring under warm sources for the nuance of the Y70R hue characterized by 5% blackness and 85% chromaticness), and as regards melanopic reflectance, is equal to 1.75 % (occurring under warm sources for the nuance of the G70Y hue characterized by 5% blackness and 30% chromaticness). This means that, for each sample, the total reflectance values calculated under the sources belonging to the same group (A, B, C, and D alternatively) do not differ significantly from each other. Therefore, for each sample, the average reflectance value can be assumed representative of the specific color under sources belonging to a given group. This is valid for both photopic and melanopic reflectance. Consequently, as mentioned in the Method section, reflectance variations discussed below are calculated through Equations 3 and 4 using, for each sample, the average reflectance value obtained within each group of sources.

Figure 4 shows the ranges of percentage differences for photopic and melanopic reflectance calculated under electric light sources for samples characterized by blackness equal to 5% and grouped according to the hue. Figures showing results for samples with blackness equal to 30% and 60% are not reported for space reasons, but results are discussed as well. It is evident that the greatest percentage differences, both for photopic and melanopic reflectance, occur under warm LED sources, whereas the lowest under the cool ones. This is valid for all the 195 samples included in the study, whatever the color attributes.

In addition, the following trends are observed under all warm, intermediate, and cool LED sources. Samples' hue is crucial for defining the amplitude of the percentage difference' ranges and if they are positive or negative. In particular, samples belonging to the R hue and to hues with yellow and red contents show variations in photopic reflectance greater than samples belonging to all the other hues, whereas samples belonging to the Y hue and to hues with yellow and green contents and with yellow and low red contents show variations in melanopic reflectance greater than samples belonging to all the other hues. In addition, nuances belonging to G70Y, Y, and Y30R hues show higher percentage differences for the melanopic reflectance rather than for the photopic one; in these cases, both ranges are positive, this means that, for each nuance belonging to these hues, both photopic and melanopic reflectance values under electric light sources are higher than those under the D65 illuminant. Also, nuances belonging to the G30Y hue show higher percentage differences for the melanopic reflectance rather than for the photopic one, but, in this case, the former range is positive while the latter is negative. Hence, under LED light sources, for each nuance belonging to this hue, the melanopic reflectance values are higher than those under the D65 illuminant while the photopic reflectance values are lower than those under the D65 illuminant. Nuances belonging to the R70B hue show a slightly higher variation for the melanopic reflectance rather than for the photopic one and both ranges are negative. Hence, under electric light, for each nuance belonging to this hue, both photopic and melanopic reflectance values are lower than those under the D65 illuminant. Nuances belonging to all the other 7 hues show, on the contrary, higher variation for the photopic reflectance rather than for the melanopic one. In particular, for nuances of the Y70R hue both the ranges are positive, whereas for nuances belonging to the B and B30G hues both ranges are negative. For nuances belonging to the R30B hue, the ranges of percentage difference for photopic and melanopic reflectance are positive and negative respectively, while the opposite occurs for nuances belonging to the G hue. Last, for nuances of the R and B70G hues the ranges of percentage difference for photopic reflectance are positive and negative respectively, while those for melanopic reflectance are almost zero. These results are observed whatever the blackness.

Samples' chromaticness affects variations in reflectance as well. Indeed, for a given blackness, the percentage difference (both for photopic and melanopic reflectance) increases as the samples' chromaticness increases. This trend is observed for all the hues.

Fig. 4 – Variations in photopic reflectance (yellow) and melanopic reflectance (blue) under warm, intermediate, and cool LED sources.

A unique correlation between samples' blackness and variations in reflectance was not found. Indeed, the highest ranges of percentage differences are observed for blackness equal to 30% for nuances belonging to the second and third quadrants (from R30B to G passing through B) and for

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blackness equal to 5% for those belonging to the first and fourth quadrants (from R to G30Y passing through Y). However, this occurs because for hues in the second and third quadrants more samples with high chromaticness are available for blackness equal to 30% rather than 5%, while the opposite occurs for samples belonging to hues in the first and fourth quadrants. This further demonstrates that chromaticness is crucial as regards variations in reflectance.

Finally, as regards the daylight illuminants (Group D), the highest percentage difference for photopic reflectance is equal to 0.35 % (for the nuance of the Y70R hue characterized by 5% blackness and 85% chromaticness) and the highest value for melanopic reflectance is equal to 0.37 % (for the nuance of the Y hue characterized by 5% blackness and 80% chromaticness). Therefore, it can be said that for each sample, whatever the color attributes, both total photopic and melanopic reflectance values are almost equal to those calculated under the D65 illuminant.

Conclusions

A new approach for lighting design, accounting for visual and non-visual effects of light, is now spreading and designers are now required to balance both aspects in their projects. In this respect, the choice of surfaces' colours is crucial since the interactions between light and materials affect the quantity, spatial, and spectral distribution of light within spaces, determining both visual and non-visual responses to light. Materials' photopic and melanopic reflectance values help designers in selecting colors for interior applications. These values are commonly calculated under the CIE D65 illuminant and reported in materials' technical sheets or in online databases. Nevertheless, both photopic and melanopic reflectance depend on the spectrum of the incident light, hence, values commonly available may not be valid anymore when the material is lit by different light sources.

To deepen this topic, 195 color samples selected from the Natural Colour System and 22 light sources (6 warm, 6 intermediate, and 6 cool LED sources, and 4 daylight CIE standard illuminants) other than the D65 illuminant are considered to carry out a systematic analysis aimed at understanding if colors reflectance values (both photopic and melanopic) vary under different light sources and what is the influence of color attributes (hue, chromaticness, and blackness) on these variations. For each sample, the variations in photopic and melanopic reflectance are evaluated by comparing the values obtained under each light source against the corresponding ones under D65.

It is found that, for each sample, reflectance values calculated under similar sources (i.e., in this study, under sources belonging to the warm, intermediate, and cool LED, and daylight group alternatively) do not differ from each other. This is observed for both photopic and melanopic reflectance. Moreover, reflectance values (both photopic and melanopic) under all the sources belonging to the daylight group are always almost equal to the corresponding values under D65. On the contrary, significant variations occur considering electric light sources. Specifically, whatever the samples' color attributes, the greatest variations, both for photopic and melanopic reflectance, occur under warm LED sources, whereas the lowest under the cool ones.

Further observations can be done considering samples' color attributes. The hue defines both the amplitude of the range of percentage difference and if it is positive or negative. The highest variations in photopic reflectance occurs for samples belonging to the Y70R hue, hence it decreases reaching pure R and it further decreases adding blue content. Then it increases again till samples of B30G hues and then decreases again. The highest variations in melanopic reflectance occurs for samples belonging to the Y hue, then, the adding of both red and green contents leads to decreasing percentage differences. For samples belonging to hues from R to G passing through B, variations in melanopic reflectance are restricted. In the main time, nuances belonging to the hues with high yellow and red content (Y, R, Y30R, Y70R, and G70R) show positive ranges of percentage differences for both photopic and melanopic reflectance, therefore, for all the nuances belonging to these hues both photopic and melanopic reflectance values under electric light sources are higher than the corresponding values under D65. The opposite occurs for nuances belonging to hues with high blue content (B, R70B, and B30G), indeed, in these cases, negative ranges are observed for both photopic and melanopic reflectance. Nuances with high green content (G, B70G, and G30Y) show positive and negative ranges of percentage difference for melanopic and photopic reflectance respectively, and the opposite occurs for samples of the R30B hue. Above all, colors' chromaticness plays a key role in influencing variations in reflectance: the higher the chromaticness, the higher the variation, both for photopic and melanopic reflectance.

In sum, reflectance values calculated under D65 are applicable under all daylight conditions or if materials are lit by cool electric light sources. On the contrary, under warm LED, colors' hue and chromaticness should be considered. Further research is needed to understand if the identified variations lead to considerable errors in design projects when colors are used in real environments.

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Why is plasmonic colour formation a game changer?

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Abstract

There are two conventional ways how colours are created: Through light falling on pigments and looking into light source itself. These kinds of colour production have some “classical“ properties. Plasmonic colours have some properties which are beyond these “classical” knowledge. In pigment colours from the incident light rays only the not absorbed ones are reflected. The combination of the reflected ones make the colour of the object surface. In light colours there are two possibilities: First the light source itself may be in certain colour(s). The second possibility is the use of colured pigment filters to filter out the colours leaving only anticipated ones. In both conventional systems (pigments and light) one cannot have light wavelenths which are not included in the light source. Plasmonic colors are based on surface plasmon resonance. Thus, colors can be created without pigment and without the need for an additional light source These plasmonic surfaces are mostly some few atoms / molecules thick. Colour is "created" without pigments. It is an engineering done with nanotechnological filters, the absorption and scattering of light. Today, with the use of software and nanotechnology at a high level, it can be used for color production for many different purposes. The fact that less energy is required to create plasmonic colors and no subsequent waste pigments make this method environmentally friendly. The nanotechnological use of plasmonic colour formation is a game changer, because it doesn`t need pigments, it has very few waste materials (which are metallic salts), it needs very thin surfaces or layers to create colours, it is more stable than conventional systems and it needs much less energy to be produced.

Keywords: Plasmonic colours, differences to pigment and light colours, game changer.

Introduction

The engineers who create the technological background or plasmonic colours and the technicians who use them for different applications esteem it as just like a surface characteristics. This paper is dedicated to the differences of the plasmonic colours to conventional colours.

Conventional colours

There are two conventional ways how colours are created: Through light falling on pigments and looking into the light source itself. These kinds of colour production have some “classical“ properties. In pigment colours from the incident light rays only the not absorbed ones are reflected. The combination of the reflected ones make the colour of the object surface. In light colours there are two possibilities: First the light source itself may be in certain colour(s). The second possibility is the use of colured pigment filters to filter out the colours leaving only anticipated ones. In both conventional systems (pigments and light) one cannot have light wavelenths which are not included in the light source.

Plasmonic color formation

Plasmonic colours have some properties which are beyond these “classical” knowledge. Plasmonic colors are based on surface plasmon resonance. Surface plasmon resonance is the resonance oscillation that occurs at the interface between the negative and positive permeability material, which is caused by the excitation of transmission light electrons in metals or photonic crystals with incident light. Thus, colors can be created without pigment and without the need for an additional light source. Simply expressed the light from the environment can be changed in its wavelength through its path on plasmonic surfaces made of metal atoms, creating new wavelengths (colours) which are not included in the incident light. These plasmonic surfaces are mostly some few atoms / molecules thick. Plasmonic colors have been used as stained glass in religious and other buildings for over a thousand years. In stained glass, some metallic salts are used to block some wavelengths of incoming light. So the color is "created" without pigments. It is an engineering done with nanotechnological filters, the absorption and scattering of light. Today, with the use of software and nanotechnology at a high level, it can be used for color production for many different purposes. Creating screen colors with plasmonic colors as a method that uses ambient light instead of LED screens, which require high energy because they use the light coming from the environment, can be seen as a near future technology. On the other hand, biosensors with surface plasmon resonance systems come into use due to their low energy requirements. Even lasers are going to be build with the plasmonic colours. The fact that less energy is required to create plasmonic colors and no subsequent waste pigments make this method environmentally friendly.

Some advantageous of plasmonic colour formation method examples over conventional colouring

With nanoscale plasmonic structures is it possible to make non-bleaching colour printing possible. (Wilson et al, 2019)

Colour generation by plasmonic nanostructures and metasurfaces has several advantages over dye technology: reduced pixel area, sub-wavelength resolution and the production of bright and non-fading colours. (Zhu et al, 2016)

Metasurface-based structural colouration shows a remarkable high colour saturation, wide gamut palette, chiaroscuro presentation and polarization tunability. (Song et al, 2023)

With plasmonic colour technology even a 1D (nanostructures are those with a dimension within the range between 1 and 100 nm) plasmonic crystals can be produced, Integrating plasmonic resonance into photonic bandgap nanostructures promises additional control over their optical properties. One-dimensional (1D) plasmonic photonic crystals with angular-dependent structural colors are fabricated by assembling magnetoplasmonic colloidal nanoparticles under an external magnetic field. (Wu et al, 2023)

Plasmonic colour utilizing the metal-insulator-metal (MIM) configuration, the generated colour is not only dependent on the geometry and transverse dimensions, but also to the size of the vertical gap between the metal nanoparticles and the continuous metal film. The complexity of conventional fabrication methods such as electron beam lithography (EBL), however, limits the capacity to control this critical parameter. With plasmonic colour via UV-assisted nanoimprint lithography (NIL) with a simple binary mould not only for structural colouration but also for other industrial applications such as high-density memory, biosensors and manufacturing can be achieved. (Shahin et al , 2020)

Color blindness, or color vision deficiency (CVD), is an ocular disease that suppresses the recognition of different colors. Recently, tinted glasses and lenses have been studied as hopeful devices for color blindness correction. *Roostaei and Hamidi (2022)* showed in their study, that 2D biocompatible and flexible plasmonic contact lenses were fabricated using polydimethylsiloxane (PDMS) and a low-cost, and simple design based on the soft nano-lithography method and investigated for correction of red-green (deuteranomaly) color blindness.

Conclusions

The nanotechnological use of plasmonic colour formation is a game changer, because it doesn`t need pigments, it has very few waste materials (which are metallic salts), it needs very thin surfaces or layers to create colours, it is more stable than conventional systems and it needs much less energy to be produced.

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Light and color: two important components of biophilic design

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Abstract

Biophilic design is an innovative approach that aims to create environmentally sustainable and less disruptive buildings and spaces by drawing inspiration from nature. Indeed, biophilic design has emerged as a discipline that seeks to create artificial environments that stimulate and support biophilia, that is the innate human connection with nature. Biophilic design recognizes the importance of incorporating nature-inspired elements and patterns into the built environment to improve human health and well-being and foster a deeper sense of connection to the natural world. The goal of biophilic design is, then, to create interiors that promote a deep sense of connection with the natural world while being environmentally friendly. By incorporating elements inspired by nature, such as plants, natural materials, and daylighting, biophilic design seeks to improve the quality of our built environment while reducing its ecological impact. Lighting and color are important aspects of biophilic design because they affect human physiological parameters and emotions and can be associated with biophilic design and its characteristics. Color preferences are the most commonly identified theme in biophilic design, and practitioners use a variety of biophilic attributes in their practice, including color, natural light, and natural materials. Lighting conditions can also influence human physiological parameters and subjective emotions, which can be applied to guide lighting design and projects. Biophilic color associations can evoke various emotions, with yellow at maximum color depth evoking the strongest experience of hope, which is an important element of well-being. It should be noted, however, that the negative influence of lighting can also be significant, as demonstrated in a pilot study in which blue light decreased people's ratings of most perceptual attributes. Thus, by understanding the influence of lighting and color on human well-being and incorporating biophilic color associations and light textures into design, designers can create spaces that promote positive mood and well-being. The purpose of this article is to explore the relationship between light and color in biophilic design, an area of research that is still being explored.

Keywords: light, color. biophilic design, biophilic patterns, biophilic lighting texture.

Introduction

Nature has always been intertwined with the health and well-being of human beings, serving as a source of inspiration for creativity. This connection stems from the fact that humans have evolved and thrived in natural environments since the beginning. Our innate affinity for the natural world is known as biophilia (Wilson, 1984), a term derived from the Greek words "philia" meaning love, and "bio" meaning life (Orr, 1993; Barbiero and Berto, 2021).

Thus, Biophilia is a scientific concept that empirically identifies a natural inclination in humans to focus on and be drawn to life and vital processes (Wilson, 1993).

Wilson's "Biophilia hypothesis" served as a profound inspiration for numerous theorists who sought to delve into this phenomenon in its various manifestations. Notably, Stephen Kellert was among the scholars who further explored and applied the implications of biophilia within the realm of design. It is this deep connection with nature that forms the basis for the emergence of biophilic design and its principles (Yin *et al.,* 2018), which seek to integrate nature into our built environments to enhance our well-being and promote sustainable and harmonious development.

In the last decade, there has been a remarkable shift in architecture, interior design and landscaping towards consideration of the real needs and well-being of the users. This shift has led to the emergence of this new discipline that recognizes our inherent need to reconnect with nature (Zhong *et al.,* 2021). Biophilic design is defined as “the deliberate attempt to translate man's affinity with nature – known as biophilia – into the design of artificial environments”. (Kellert *et al.,* 2008). It seeks to create spaces where reciprocity, respect and enriching relationships between humans and nature can exist as the norm rather than the exception. (Kellert *et al.,* 2008). Biophilic design isn't just a passing trend; it is an applied science that transcends aesthetics. This discipline embraces various aspects of design and takes into account the real needs of the users, considering how these spaces can best support their well-being by incorporating elements of nature. Biophilic design principles can include incorporating natural materials, using daylight and views of nature, incorporating natural shapes and patterns and creating sensory experiences that evoke nature.

A holistic approach to interior design acknowledges the significance of color and light as crucial sensory considerations within interior environments (Poldma, 2009). These three factors are interconnected within the design process and coexist within a space. However, when we consider biophilic design there is limited understanding of how color and light elements are specifically applied in relation to biophilic features and the existing research supporting the incorporation of biophilic elements. What is certain is the relationship between application and evidence in biophilic design within color and light is grounded in research that demonstrates the impact of these elements on human psychology and physiology. By integrating appropriate colors and lighting strategies informed by this evidence, biophilic design aims to create spaces that uplift mood, improve productivity, and enhance the overall quality of life for occupants.

The principles of Biophilic design

Biophilic design recognizes the profound impact of biophilia on human well-being and seeks to incorporate this understanding into architectural design principles. Stephen Kellert highlights the growing disconnect between modern architecture and the inherent needs of human nature, particularly the need to connect with nature (Kellert, 2005). Biophilic design aims to restore this connection, recognizing that it is vital for enhancing mental health, productivity and human well-being (Kellert *et al.,* 2008).

In contemporary architecture, there has been a tendency to prioritize functionality and aesthetics without adequately considering the psychological and physiological benefits that nature provides. This detachment from nature has led to a growing disconnect between humans and their built environments, which can have negative effects on overall well-being (Kellert, 2005).

Biophilic design responds to this challenge by intentionally integrating elements of nature into the design process. It goes beyond simply incorporating visual aspects of nature and encompasses a broader range of sensory experiences, such as the use of natural materials, the incorporation of natural light and views, the inclusion of textures, and natural patterns.

Through the implementation of biophilic design principles, architects and designers can create spaces that reconnect individuals with the natural world, fostering a sense of harmony and balance.

Biophilic design not only emphasizes the human-nature connection but also recognizes the importance of environmental sustainability. While the current approach to sustainable design focuses primarily on scientific and technical aspects, such as energy efficiency and material selection, it often overlooks the psychological and emotional aspects of ecological responsibility. Biophilic design bridges this gap by incorporating the human element into sustainable design (Andreucci *et al*., 2021). It recognizes that humans are not only rational beings but also emotional and sensory beings who thrive in nature. By integrating natural elements and patterns, biophilic design aims to evoke a heightened sense of responsibility and appreciation for the environment and encourages a sense of awe, tranquility, and well-being, which can inspire a stronger commitment to preserving the environment.

Incorporating biophilic design principles into sustainable architecture and design can create spaces that not only reduce environmental impact but also enhance the overall human experience (Nasr Aly Tahoun, 2019). By addressing the psychological and emotional aspects of ecological responsibility, the biophilic design promotes a holistic approach to sustainability, engaging individuals on a deeper level and inspiring a greater sense of stewardship for the environment.

Toward the practice of Biophilic Design: Dimensions, Elements, and Attributes

Biophilic design draws upon the evolutionary roots of biophilia to identify design elements that restore the connection with nature but it recognizes that not all natural features automatically have a positive effect on human well-being. Still, there are also natural features that could pose dangers and elicit negative physical responses like stress (Gullone, 2000). It is crucial to distinguish between beneficial and stressful natural features when incorporating them into the design: not everything that is natural has always a beneficial effect on people's well-being.

To try to give a detailed understanding of biophilic design to designers, Kellert identifies dimensions, elements, and attributes of this discipline. “The first dimension of biophilic design is organic or naturalistic defined as shapes and forms in the built environment that directly, indirectly, or symbolically reflect the inherent human affinity for nature" (Kellert, 2008). This can be achieved by introducing natural elements such as daylight or views of the natural environment (direct), incorporating potted plants (indirect), or using representations of nature like images or metaphors (symbolic). The second dimension is a place-based or vernacular defined as "buildings and landscapes that connect to the culture and ecology of a locality or geographic area" (Kellert, 2008). By integrating elements that relate to the natural environment and cultural context, the building becomes an integral part of the residents' individual and collective identity. This approach ensures that the design aligns with the characteristics and values of the community, fostering a sense of belonging and connection to place. Without a deep understanding of one's surroundings, it is likely that the place will be treated carelessly and eventually degraded (Berry, 1972).

Kellert, in relationship with the two dimensions, developed a list of 72 characteristics, called attributes and grouped into six categories, known as elements (Kellert, 2008). These attributes range from the simple presence of water, air, sunlight and plants to more intricate and multifaceted elements (conceptual attributes) to complex attributes, such as “ecological identity” and “cultural and local context” (abstract attributes). A focus is to be made on two abstract attributes: sensory variability and information richness. The first abstract attribute refers to the incorporation of a range of sensory stimuli in the design. By engaging multiple senses, the environment becomes more dynamic and engaging, mimicking the sensory richness found in nature. The visual sense is the main way people perceive and respond to the natural world. Whereas the information richness attribute aims to provide a stimulating and intellectually captivating environment by incorporating elements whit a wealth of information, such as patterns, textures, and natural materials.

A key aspect for biophilic designers to understand is that the environment can encompass more than just physical elements. It can also be an atmosphere or an experience. Biophilic design goes beyond the mere presence of natural elements and seeks to create spaces that evoke a sense of place and generate a meaningful and positive lived experience (Andreucci *et al*, 2021). Kellert himself highlighted the challenges that designers face when translating conceptual and abstract attributes of biophilic design into practical design solutions. These difficulties arise due to the complex nature of biophilic design principles and the need to translate them into tangible and implementable design elements. As a result, simplifications and improvements in Kellert's theory became necessary. In 2015, Kellert and Calabrese reworked the 72 design attributes, making changes to make them more easily applicable to the architectural design process. The streamlined framework now includes just three categories and 24 attributes. These three fundamental categories of nature experiences serve as the cornerstone of our approach.

Categories and Patterns in Biophilic Design

The challenge posed by biophilic design lies in addressing the shortcomings of contemporary architecture and landscape practices, paving the way for a fresh framework that nurtures a fulfilling experience of nature within the built environment (Kellert *et al*., 2008, Kellert, 2005, Browning *et al*., 2014). Therefore, it seeks to bridge this gap by integrating nature into our surroundings, reestablishing a harmonious relationship between humans and their built spaces. Today we have tools that are commonly used in the field of biophilic design that offer designers frameworks and guidelines to incorporate biophilic design principles effectively. An example of revision of Kellert's attributes is study by Terrapin Bright Green published the guide "14 Patterns of Biophilic Design: Improving Health & Wellbeing in the Built Environment" (Browning et al., 2014). The authors take the concepts of Wilson, and the patterns of Kellert and Calabrese and incorporate a wide range of scientific research that demonstrates how exposure to natural elements can improve the physical and mental health of people in built spaces. These 14 patterns are organized into three categories that provide a comprehensive structure for understanding and implementing biophilic design principles in the built environment: Nature in Space Patterns, Nature Analogues Patterns, and Nature of Space Patterns (Browning *et al.,* 2014, Ryan 2014).

1. Nature in Space Patterns involve the incorporation of actual natural elements into the built environment, such as water, plants, and animals. This category includes patterns such as "Visual Connection with Nature," "Non-Visual Connection with Nature," and "Dynamic & Diffuse Light."
2. Nature Analogue Patterns involve the incorporation of representations or imitations of natural elements into the built environment, such as artwork, materials, or colors that mimic natural patterns. This category includes patterns such as "Biomorphic Forms & Patterns", "Material Connection with Nature", and "Complexity and Order".
3. Nature of Space Patterns focus on designing spaces that evoke the feeling of being within natural environments, such as spaces that have a sense of prospect or refuge. This category includes patterns such as "Prospect", "Refuge", "Mystery" and "Risk/Peril."

This revised framework offers a comprehensive and updated understanding of the principles and patterns of biophilic design and aims to refine and expand the practical application of biophilic design providing designers a more comprehensive toolkit to effectively integrate biophilic elements into their projects and create spaces that enhance well-being, health, and connection to nature.

"People's physical and mental well-being remains highly contingent on contact with the natural environment, which is a necessity rather than a luxury for achieving lives of fitness and satisfaction even in our modern urban society" (Kellert, 2008).

The incorporation of biophilic design principles, specifically in terms of color and light, is an area that is still being explored and understood by interior designers and researchers. While there is growing recognition of the importance of color and light in creating biophilic experiences, the specific guidelines and best practices are still evolving.

Biophilic Design and the perception of the environment

Perception is intimately connected to the neurological processing of visual information. One of the main factors that can influence perception is the atmosphere of a given space. Biophilic design not only involves changes to the internal atmosphere but also offers the opportunity to transform the internal environment by connecting it to the external environment in a sensorial way (Dalay, 2020). The incorporation of biophilic design principles allows for a holistic approach to interior spaces, where the lines between inside and outside are blurred. Every design decision, from large windows offering expansive views of the surrounding natural landscape to an interior garden or vertical green walls, to the use of water features, plays a significant role in shaping the interior atmosphere through external factors.

We need light to perceive our surroundings and we need light to create atmosphere.

The introduction of daylight into interiors or the correct use of artificial light has a transformative effect on the atmosphere of a space and can also be complemented by strategic design decisions involving color and the use of materials such as reflective surfaces.

It is possible to create a biophilic atmosphere in the space by using color. Color is a concept that possesses the ability to elevate the human experience and transform spaces. The use of color is a crucial design element that plays a significant role in shaping the atmospheric perception of a space. "We are surrounded by an ever-changing color palette in nature that inspires the principles used in the creation and selection of materials for interior design" (Bosch *et al*., 2012). Color can be seen as a nature-inspired element within the material components of a space.

Therefore, light and color play a vital role in biophilic design as they have a profound impact on our perception, mood, and well-being and contribute significantly to creating a connection with nature. However, we only see color because we have light. (McGee and Park, 2022)

Light in Biophilic Design

There is a clear connection between the concept of biophilia and the pursuit of replicating natural light qualities in artificial lighting. Light occurs both as an attribute in Kellert's experiences and as a pattern in Terrapin's categories. Kellert highlights the significance of light as a key element that influences human well-being and our connection to nature. He acknowledges that light, both natural and artificial, plays a fundamental role in shaping our perception of spaces and our overall experience within them. Natural light, Kellert argues, goes beyond mere functional aspects and can create aesthetically appealing effects through the interplay of light and shadow, diffused and variable lighting, and its integration with spatial qualities. Creative manipulation of light and using light textures can result in visually appealing shapes that enhance the ambiance of a space. Kellert also acknowledges the importance of artificial lighting in creating biophilic environments, pointing out that "artificial light can be designed to mimic the spectral and dynamic qualities of natural light" (Kellert and Calabrese, 2015).

Regarding Terrapin, the Dynamic & Diffuse Light pattern recognizes the significance of natural light and seeks to emulate its qualities in indoor environments following two primary objectives. Firstly, it aims to offer users a range of lighting options that engage and captivate the eye, promoting a positive psychological and physiological response. Secondly, it seeks to support the proper functioning of the circadian system, which regulates our sleep-wake cycle and other biological processes.

"The goal should not be to create uniform distribution of light through a (boring) space, nor should there be extreme differences (i.e., glare discomfort)" (Browning *et al.,* 2014). Dynamic lighting can be achieved by incorporating elements such as adjustable fixtures, dimmers, or automated lighting systems that allow for varying light levels, color temperatures, and patterns throughout the day.

Diffuse lighting is another important aspect of the pattern: "Diffuse lighting on vertical and ceiling surfaces provides a calm backdrop to the visual scene." (Browning *et al.,* 2014) This lighting layout involves distributing light evenly throughout a space, reducing glare and harsh shadows. Even accent lighting and task or personalized lighting are fundamental to obtaining a correct lighting project. By incorporating these layers of lighting, designers can create a pleasing visual environment. The combination of diffuse lighting, accent lighting, and the task or personalized lighting creates a balanced and harmonious interplay of light (Clanton, 2014).

When designing a space, it is important to establish a balance between dynamic and diffused lighting conditions. Key considerations to achieve this balance are:

1. Dynamic lighting conditions can be utilized to facilitate a smooth transition between indoor and outdoor areas. By carefully controlling the intensity and color temperature of the lighting, designers can create a sense of continuity and connection with the surrounding environment.
2. Spaces, where activities requiring directed attention are performed, may not be suitable for drastically dynamic lighting conditions. Rapidly changing colors, direct sunlight penetration, and high contrasts can be distracting and disrupt concentration.
3. Spaces, where people spend extended periods of time, can benefit from circadian lighting.

By incorporating dynamic and diffuse lighting into the design, therefore the pattern aims to enhance the user's experience, improve mood, and support their physiological needs. The pattern also allows for customization based on individual preferences and activities within a space.

Color in Biophilic Design

Visual perception, as a sensory experience, has a deep connection with our emotions. Colors have the characteristic of arousing purely subjective emotions, feelings, and meanings, which can vary according to perception and cultural experience. Throughout the day, our perception of colors is

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intimately linked to the ever-changing hues of light and is profoundly influenced by the ever-changing colors of natural elements. Colors have been critical to human evolution and survival, as they enhance the ability to locate resources such as food and water and to identify hazards. (Barbiero *et al*, 2022; Salingaros, 2015). Both Kellert and Terrapin refer to the essence of nature through representations and evocative stimuli as nature-inspired artwork, textures, and materials that mimic the visual and tactile qualities of the natural world. Natural colors are one of Kellert's attributes and play a significant role in biophilic design, as they evoke a sense of connection to the natural environment and contribute to our well-being. However, in the modern world, the abundance of artificial and overly bright colors poses a challenge to the effective use of color in the built environment. In biophilic design, the color application should generally favor muted, earthy tones that reflect the characteristics of the soil, rocks, and plants. While the use of bright colors is not discouraged, it should be approached with caution and used selectively to highlight specific environmental elements, such as flowers, sunsets and sunrises, rainbows, and certain plants and animals. By strategically incorporating these vibrant pops of color, designers can add visual interest and create focal points that grab attention and evoke positive emotions associated with the natural world. However, it is important to avoid excessive use of highly artificial colors in biophilic design. These colors can disrupt the overall sense of harmony and tranquility that biophilic spaces aim to achieve. Instead, the goal should be to create a balanced, natural color palette that complements other biophilic design elements and promotes a deep connection with your surroundings.
There is no pattern among the 14 patterns of Biophilic Design only on color. The use of natural materials or materials that mimic the qualities of nature is the object of the Material Connection with Nature model. This pattern has indeed evolved based on scientific research that explores the physiological and psychological responses to natural materials and the impact of natural color palettes on cognitive performance (Browning *et al*, 2014). Regarding physiological responses to natural materials, research has shown that exposure to natural materials, such as wood, can have positive physiological effects on individuals. On the other hand, when the wood coverage is wide (approximately 90% coverage), a decrease in brain activity was observed. This finding suggests that in spaces where high cognitive functionality is expected, such as offices, a high dose of wood may not be conducive to optimal cognitive performance. Regarding the impact of natural color palette, the color green has been extensively studied in relation to its impact on cognitive performance concluding that exposure to the color green "facilitates creativity performance, but has no influence on analytical performance" (Lichtenfeld *et al*., 2012). It has been documented that humans possess a superior ability to discern variations in the color green in comparison to other colors (Painter, 2014). Nevertheless, the specific variations of green that most significantly influence creativity or other mind-body responses remain largely unknown.
Design considerations of this pattern include the following:
1. The quantity of natural material and the choice of color in a space depends on its intended function. Similarly, it is recommended to introduce a degree of variability in the materials and colors and their applications rather so as to allow for a richer and more diverse sensory experience.
2. Real materials are preferred over synthetic ones because they have an intrinsic authenticity and can elicit a stronger sensory and emotional response.
4. Adding instances of the color green can positively affect creative spaces.
It is important to note that while the impact of natural materials and colors on physiological and cognitive responses has been studied, individual preferences and cultural influences also play a role. Designers should consider the specific context, user needs, and cultural aspects when applying the Material Connection with Nature pattern and selecting materials and colors for a biophilic design.

Conclusions

One crucial consideration in biophilic design is the recognition of atmospheres, ambiances, and energies to promote human health and well-being. By considering these aspects, the biophilic design strives to go beyond functionality and aesthetics alone and becomes more than a visual

concept; it becomes a transformative and feel-good lived experience for individuals within the space. This involves understanding and intentionally creating the desired emotional and sensory qualities within a space.
Additionally, biophilic design acknowledges the importance of experiences within the built environment. It seeks to create spaces that engage and stimulate individuals, encouraging exploration, discovery, and a sense of connection to nature. By carefully selecting materials, colors, lighting, and other design elements, we can shape the atmosphere to evoke specific feelings.
The relationship between color, light, and biophilic design is a dynamic and essential aspect of creating sustainable, healthy, and inspiring built environments. It's important for designers to consider the specific context, user preferences, and project objectives when incorporating light and color in biophilic design. Applying a combination of natural light, dynamic lighting systems, nature-inspired colors, and an understanding of color psychology can help create indoor environments that foster a stronger connection to nature and enhance occupants' well-being.
Today biophilic design offers us an opportunity to transform the indoor atmosphere by connecting it sensually to the outdoor environment. By incorporating visual, tactile, and auditory elements from nature, the interior space can be enhanced, creating a more immersive and emotionally engaging atmosphere.

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Physiology and psychology of light and colour: evaluation of an experimental approach

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Abstract

The application of light and colour studies for human well-being is a promising field in design. While good lighting practice is a critical factor in promoting safety and well-being in the workplace, the potential benefits of using light and colour to influence mood and physiology are yet to be fully explored. Since the discovery of ipRGCs and their role in regulating the circadian cycle, new possibilities have been presented to designers to create environments and products that promote well-being, better mood and improved performance.

Studying the effects of light and colour on psychology and physiology implies understanding the process of vision and its influence on factors such as circadian regulation and mood. Bridging the gap between psychology and physiology is crucial to harnessing these mechanisms for positive outcomes. This process involves three interconnected brain systems: perception, cognition and emotion. Perception is the fundamental system which extracts hierarchical and increasingly complex information from the neural codes of the stimulus. Cognition integrates this information with prior knowledge to create a meaningful representation of the environment. Emotional evaluation occurs concurrently with cognition and influences preferences and behaviour based on the affective valence of the processed information.

Recent studies have shown that humans' perception of colours is influenced not only by visual factors but also by physiological processes. Although, for example, warm and bright colours such as yellow and red are commonly associated with an "activating" effect, while physiologically activating colours are at the opposite end of the spectrum (blue), how this process occurs at the "perceptual" level is not yet well defined. By exploring the relationship between colour and emotion and its potential effects on physiology, designers can create environments or products suited to specific needs, such as promoting relaxation or increasing concentration and alertness.

In this paper, we will describe the process of evaluating various factors and issues in the creation of a practical experiment for the verification of the possible existence of a predictable correlation between physiology and psychology regarding the perception of light and colour from the various psychological biases that can affect the results to the experimental conditions, to obtain results that can be declined in a real lighting design context.

The potential applications of light and colour studies in design are vast and diverse. Lighting design can create engaging spaces that promote well-being. In product design, colour and lighting can enhance the functionality of luminaires to improve many physiological aspects and the appeal of areas. Combining physiology and psychology in this field may enable the creation of elements that enhance daily life. As we learn more about these topics, the possibilities for tailored design will continue to grow.

Keywords: Light, Colour, Physiology, Psychology, Design.

Introduction

The application of light and colour studies for human well-being is a promising field in design. Good lighting practice is crucial for promoting safety and well-being in the workplace. Still, the potential benefits of using light and colour to influence mood and physiology are yet to be fully explored (Siniscalco, Bortolotti and Rossi, 2022). The discovery of ipRGCs (intrinsically photosensitive retinal ganglion cells) and their role in regulating the circadian cycle has opened up new possibilities for designers to create environments and products that promote well-being, better mood, influence behaviours -purchasing or not- and improved performance (Bortolotti *et al.*, 2022, 2023). In order to understand the effects of light and colour on psychology and physiology, it is essential to comprehend the process of vision and its influence on factors such as circadian regulation and mood (Rossi, 2019). This involves three interconnected brain systems: perception, cognition, and emotion. Perception extracts complex information from the stimulus; cognition integrates it with prior knowledge to create a meaningful representation of the environment, and emotional evaluation influences preferences and behaviour based on the affective valence of the processed information (Morrone, Denti and Spinelli, 2002; Pratte *et al.*, 2013).

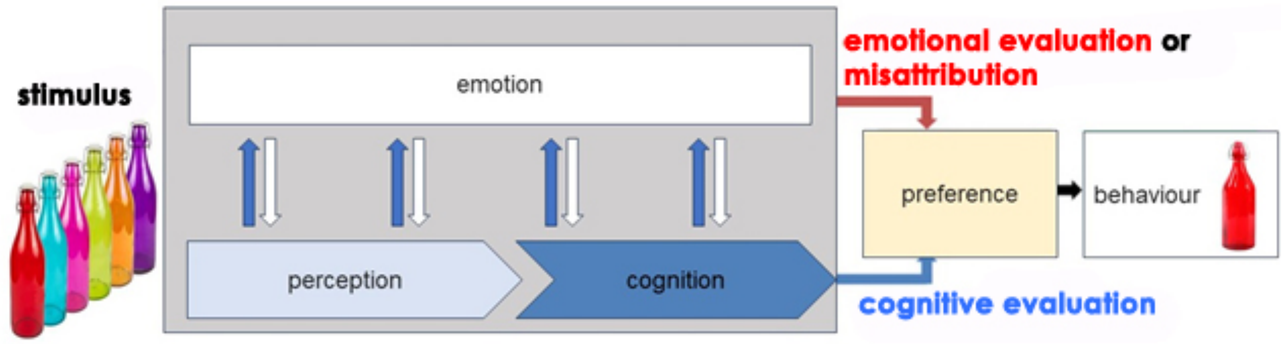

Fig. 1 - Information processing in animal brains (Renoult and Mendelson, 2019)

This perceptual process and the resulting mental representation of colour cannot but depend on light. Light is pivotal in vision and overall well-being, as it synchronises our physiological processes with the natural day-night cycle. Its impact is far-reaching, influencing various physiological and behavioural responses, from hormonal rhythms and the pupillary response to sleep quality, alertness, cognitive performance, and mood (Cajochen, 2007). However, it is essential to note that most of these effects have been studied in controlled laboratory conditions under artificial light, which may limit their general applicability to real-world scenarios. Ideally, studies utilising natural daylight are required, though technical challenges and inherent variability pose a significant obstacle. While the intuitive preference for daylight over artificial light holds, we lack sufficient data to substantiate this claim conclusively. In the present context of 24-hour lit environments, ensuring adequate darkness during the night becomes crucial to prevent circadian phase shifts that can disrupt restorative sleep, a fundamental aspect of maintaining good health. To comprehensively comprehend the effects of light on physiological and psychological processes, we must consider various factors, including the characteristics of the light, the individual's status, personality, living conditions, and cultural influences, along with the intricate interplay of functional brain systems.

Implementing daylight effectively into the spaces of living can be achieved through various means. The development of cutting-edge technologies in the dynamic and online control of lighting products allows designers an ever-increasing level of integration of artificial light with natural light and the process commonly known as "daylight harvesting" (Kandasamy *et al.*, 2018). Encouraging people to spend more time outdoors can be accomplished by providing sheltered outdoor spaces and seating in cities and allowing flexible work schedules that permit regular outdoor breaks during

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daylight hours. However, successfully integrating these strategies necessitates cultural and climatic awareness, political support, public backing, and education. Additionally, disseminating knowledge about the significant non-visual aspects of daylight is vital. Embracing the challenge of meeting our light needs is a captivating endeavour for society. We are only just beginning to realise the profound importance of daylight for humanity's health and well-being.

Recent studies have revealed that humans' perception of colours is influenced not only by visual factors but also by physiological processes. For example, warm and bright colours like yellow and red are commonly associated with an "activating" effect, but physiologically activating colours are at the opposite end of the spectrum (blue). Understanding how this process occurs at the perceptual level is not yet well-defined (Gao and Xin, 2006; Siniscalco, Bortolotti and Rossi, 2022). By exploring the relationship between colour and emotion and its potential effects on physiology, designers can create environments or products suited to specific needs, such as promoting relaxation or increasing concentration and alertness.

Colour physiology and psychology

What has been said, let us imagine the complex system of "human beings" that has to process a light (or coloured, if you will) stimulus. The perception of these coloured stimuli, we could define them as highly complex stimuli because of their nature composed of different variables in action. Within this intricate study lies a central challenge: the complex nature of the human perception process. We will attempt to explain and break out of this labyrinthine terrain to unravel the intricate workings of how colour stimuli interact with the human psyche. Colour perception and its emotional impact are multifaceted and influenced by many variables, including cultural background, personal experiences and physiological responses (Elliot and Maier, 2012).

This work seeks to shed light on the intricate web of factors that contribute to our emotional reactions to colours. As part of this research, we aim to define and understand the complex stimuli presented by colour in the context of human perception. These stimuli are inherently intricate because of their composition of several interacting variables, making understanding their emotional impact a formidable challenge.

The primary goal of this paper is to clarify the intricate process of evaluating the multitude of factors and complexities involved in conducting a pragmatic experiment to study the connection between colour and emotion. They will meticulously examine the impact of psychological biases on the results and carefully calibrate the experimental conditions. We intend to produce results that can be easily applied in practical lighting design scenarios and various fields where colour plays a crucial role in evoking emotional responses. One central issue this research addresses is the inherent subjectivity of colour perception and its emotional effects. Colours evoke unique emotions and associations in different individuals, often rooted in cultural, personal and psychological factors. This paper aims to navigate this complexity, seeking to identify patterns and correlations in how various colours influence emotional states in diverse populations. This "emotional" subjectivity of colour perception makes knowledge of variables such as the context or culture of reference of the person perceiving a given colour at a given time of paramount importance. In this regard, different theories have already been examined in reviews of the literature (Bortolotti *et al.*, 2022); the most credited theories regarding colour preference from a psychological perspective only the EVT (Palmer and Schloss, 2010) and the Color in context theory of Elliot and Maier (2012).

The "Ecological Valence Theory" (EVT) seeks to show the importance of colour preferences in various aspects of human life, such as buying cars, choosing clothes, decorating the home and designing websites. Although previous studies have described colour preferences from a psychophysical perspective, they have not explained why people have these preferences or like specific colours. The EVT argues that human colour preferences are adaptive in that people are more likely to thrive and reproduce if they are attracted to colours associated with advantageous objects and repelled by those related to disadvantageous objects. EVT combines genetic and learned components: individuals develop colour preferences based on their affective responses to coloured objects throughout their lives. The theory is being tested to determine its ability to explain average colour preferences among individuals for a wide range of colours. The EVT suggests that people should be attracted to colours associated with objects that generally evoke positive emotions and repelled by colours associated with objects that evoke negative emotions. This prediction is compared with other theories, including the cone-opposite contrast model, color appearance theory and color-emotion theory. This theory is most applicable to design and our vision of well-being.

On the other hand, the colour in context theory (Elliot and Maier, 2012) already discussed the shortcomings in the current state of research on colour and its impact on psychological functioning. It emphasises the need for a more rigorous and standardised approach to studying the relationship between colour and psychology. The theory highlights three main weaknesses: **Lack of Proper Color Control**: Many studies do not adequately control colour properties, often only addressing them at device level rather than the spectral level. This lack of control can lead to interpretational ambiguity and undermine the scientific validity of the findings. Proper colour control, although challenging, is deemed essential for rigorous scientific work in this field. **Neglect of Environmental Factors**: Color perception is influenced by various environmental factors such as viewing distance, lighting conditions, and the presence of other colours. Basic colour science research carefully accounts for these factors, but psychological research often ignores them. The theory argues for incorporating rigorous standardisation procedures used in basic colour science research to enhance the quality of psychological studies. **Underpowered Samples**: Many studies in this area suffer from small sample sizes, which can lead to overestimated effect sizes and premature conclusions. The theory stresses the importance of using large, fully powered samples to ensure robust and reliable scientific results. It also encourages adopting best practices from the "evidentiary value movement," such as public archiving of research materials and data, differentiating between exploratory and confirmatory analyses, and preregistering research protocols and studies. In summary, this theory calls for a more meticulous and standardised approach to researching the connection between colour and psychological functioning, addressing issues related to colour control, environmental factors, and sample sizes. It emphasises the importance of adhering to current technological limitations while striving for precise and efficient colour management in research.

These two pieces of research alone would be enough to explain, from our point of view, the problems related to a proper investigation of the study of colour or light on psychological well-being related to colour perception. Still, we will try to explain everything in detail.

Evidence-related issues

Starting from the limitations listed above, also examined in Elliot's study, i.e., lack of proper colour control, in this case, different studies and literature reviews (Bortolotti *et al.*, 2022) have highlighted the issue in this methodological problem would cause all the errors made regarding not only the correct description of the stimulus, but, also the whole experimental part related to the correct presentation of the coloured stimulus (think of a fixed distance from a point x at 0.5 m from a screen and the same stimulus presented at a distance of 1.5 m) the colour perception is also affected by these distances, or the resolution of a pc screen, etc. In many studies in this field, the precautions taken are not meticulously described. These limitations, also indicated in the study mentioned above, relate to the other issues shown by Elliot, i.e. neglect of environmental factors; this, in

particular, also concerns the contamination of the survey colour, often not “administered” correctly. The last point shown by Elliot is the underpowered samples; in this case, the sample size is the component that affects the data most of all. To these limitations, however, we must add others; this paragraph addresses the multifaceted challenges associated with chromatic perception testing. It spans various aspects, from the development and design of tests to ethical considerations. The complexities and intricacies within this domain necessitate a comprehensive examination of these issues.
Developing precise tests for chromatic perception is a pivotal step that requires a comprehensive understanding of various intricate factors. The interplay of these factors, including colour sample selection, representation methods, presentation techniques, and the formulation of explicit test objectives, plays a crucial role in determining the efficacy of the resulting tests. Failing to navigate these complexities can have profound implications for the reliability and validity of the outcomes.
Standardization: Achieving test standardization is pivotal to ensure consistent and comparable measurements across individuals and diverse populations. However, standardization can be challenging, especially when accounting for cultural variations in colour perception.
Validation and Norms: To ascertain the validity of a chromatic perception test, validation studies must demonstrate that the test effectively measures its intended construct. Furthermore, establishing norms for result interpretation, often based on reference population samples, is crucial.
Cultural Sensitivity: Color perception can exhibit substantial variation across different cultures. Thus, chromatic perception tests must be sensitive to these cultural differences to prevent cultural bias from infiltrating the results.
Ongoing Assessment: Given that colour perception can change with age or due to ocular pathologies, continuous assessment should be integrated into tests to monitor potential variations over time.
Bias Prevention Education: Test administrators must receive adequate training to prevent the introduction of bias during test administration and result interpretation. Knowledge of potential sources of error is imperative.
Practical Applications: Ultimately, the results of chromatic perception tests find applications in various practical domains, such as product design, art, medicine, and more. Considerations about the practical implementation of these results should be carefully examined.
The problem of classifying colour-emotion associations: The conceptual metaphor theory (Lakoff and Johnson, 1980) can explain the association between colour and emotion. According to this theory, humans apply the structures of other concrete concepts to the target abstract concepts to understand abstract concepts related to thought and action. Therefore, concepts related to emotions, which lack clear boundaries, are understood using colour concepts as scaffolding, as colours are clear perceptual experiences (Sowa, 1999; Williams, Huang and Bargh, 2009). In other words, the metaphorical structures of concepts like “sadness is blue” and “anger is red” facilitate the comprehension of emotion-related concepts.
To recap, there are numerous challenges associated with chromatic perception testing, encompassing technical aspects of test design and ethical and cultural considerations. Addressing these challenges is imperative for obtaining valid and practical insights into chromatic perception.

Conclusions

The number of variables to consider when evaluating human emotions is very high. As mentioned, on some occasions, the psychological response appears to manifest opposite to the typical mechanisms of physiological reaction to light and colour. One plausible hypothesis for why these two paths may appear misaligned is that the physiological response primarily follows non-visual means, which therefore do not involve higher-level processing by the cerebral cortex, while emotions, albeit uncontrolled, result from the brain’s visual stimulus processing.
Regarding the physiological response, melanopsin predominates at the retinal level as the stimulus receptor (Provencio et al., 2000). Subsequently, following phototransduction, electric impulses are

transmitted through the retina-hypothalamus pathway, processing in the suprachiasmatic nucleus and the response of the pineal gland (controlling melatonin and the circadian rhythm). On the other hand, in response to coloured stimuli, cones operate phototransduction, transmitting impulses through the optic nerve and forming the percept in the posterior cerebral cortex. However, it is demonstrated that cones (visual path) also play a role in synchronizing the circadian cycle (Bhoi *et al.*, 2023). Therefore, it is reasonable to assume that a form of proportionality may exist between the two aspects of the human response to light and colour.

As one can easily imagine, designing a test to assess emotional responses in subjects is a highly complex endeavour. Furthermore, avoiding the pitfalls highlighted by Elliot and Maier entails using a substantial number of subjects and preparing a test setup considering numerous factors. Simply observing a colour on a screen or through a viewer can yield results; however, in practical terms, the emotional response to a simple coloured stimulus may differ from that of the same colour applied, such as ambient lighting in an actual environment. The type of space itself can affect test subjects psychologically. The presence or absence of another person in the test area (an expedient that could also reduce time requirements) can impact the results. The psycho-physical state of the subjects is equally crucial; pre-existing factors such as fatigue, boredom, stress, or excitement can also exert an influence. How many hours did the subject sleep? What is their age, gender, profession, etc.?

If the test were conducted in a potential mock-up of space (rather than using a viewer or monitor), how much would the geometry of the room and the choice of furnishings and objects influence the outcome?

Regarding the choice of colours, it would be possible to illuminate the environment with a single colour at the time to identify subjects' reactions in the most unequivocal manner possible. However, under normal living conditions, it is infrequent to be in environments illuminated monochromatically. The presence of multiple colours can create harmonies or contrasts. The opponent process theory (Ering, 1964), which is observed not only in the visual perception of colours but also in the inhibition of melatonin (Figueiro *et al.*, 2004), suggests that it would be advisable to consider environments that present non-monochromatic visual stimuli as well. When evaluating saturated colours, even if they are "pleasing" according to models like the EVT, what emotional reaction do they provoke in subjects when they alter the perception of everyday objects? For example, think of food chromatically transformed by coloured light: pasta illuminated in purple, fish in yellow, chicken in red, etc.

Considering that several variables impact the time required to conduct the test on each subject, it is clear that it is challenging to address the issues described in the second paragraph.

One approach to addressing the problem could be to start with an initial set of tests using an appropriately calibrated screen or VR headset to present defined colours at a predetermined focal distance. The tests should be open to as many participants as possible, considering variables related to the subjects (age, gender, physical conditions, presence of medical conditions, etc.) and the chromatic stimulus (spectral power distribution, duration, luminous intensity).

Fig. 2 - On the left, an adequately calibrated VR display could deliver coloured light to the test subjects. On the right is a mock-up of a typical living environment illuminated by dynamic coloured lights.

The early assessment of the obtained psychological response will then be cross-referenced with the results of a second series of tests, ideally conducted in a neutral environment rebuilt and illuminated with a dynamic lighting system. In the second series of tests, luminous scenarios known to elicit physiological responses in humans, in terms of activation and stress (Cajochen *et al.*, 2005) as well as relaxation (Noguchi and Sakaguchi, 1999), will be tested using coloured lights and different shades of white light (correlated colour temperature). This procedure will also allow the evaluation of possible proportional relationships between the two mechanisms.

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What is different and special in pyrogenic (firework) colors?

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Abstract

Pyrogenic colours (best examples are fireworks) have its own perception rules. The colour making and perception in fireworks is different from normal colour perception. In pyrotechnique different metal salts are "burnt" in a short time, so their coloured flames can be seen. The most known colours of metal salts are barium with bright greens; strontium yields deep reds; copper produces blues and sodium yields yellow. Mixing elements can cause new colours like in strontium and sodium brilliant orange; titanium, zirconium, and magnesium silvery white. Copper and strontium make lavender. These flame colours are not known in every day life. Watching them at a dark background (night sky) make them look magnificient. Humans perceive colours normally looking at pigments where light falls on or mixing lights. Normally humans do not look into light sources directly. The exception to that is looking into fires in history (where are only yellow and red colours) and today looking into the digital screens. The colour effect of flames of metal salts burnt in a short time make the fireworks, which is rarely seen in nature. Colour perception by looking into the light source (flames) is exceptional way of seeing for humans also.

Keywords: Pyrogenic colours, firework colours, flame colous, metal salts, looking into the light source

Introduction

The invention of fireworks igoes banck to 9th century and it is credited to the Chinese. Over the centuries, pyrotechnicians (fireworks experts) refined the design of fireworks, introducing new colors, shapes, and effects. With today's technology, fireworks displays can be created in many different colors by briefly detonating metal salts of various colors as a black or dark blue sky background.
This colorful show, which has been in the sky for centuries, impresses the audience and makes them watch it again and again with pleasure. It would be appropriate to examine this visual effect, which has been affecting people for centuries, both in terms of color technology and visual perception.

Looking at dark parts of a scene and its visual perception

Human visual perception can't be described objectively. It is different from photography or videos. Many hardware and software techniques try to mimic human perception. One of the qualities of human vision is, that it can adapt to different lights levels in milliseconds. These different light levels may be in neighbourhood of the fixation point or in different parts of the human visual field. If there are deep shadows, it is perceived at first as black. But if the eye fixates for milliseconds in that part of the visual field, illumination perception changes at that area. Details and colours in that area can be "seen" by the brain. So the perception of the environment by a taken photo maybe very different from that which is perceived by the eye / brain. This effect is being tried to be eliminated by the use of HDR (high dynamic range) softwares.

Looking at a dark or black background

If humans look at the sky when the fireworks are fired, Taken fixate on the coloured flames which are caused by the fireworks. At that moment you they cannot fixate anything in the deep black background (the sky). So the chiaroscuro effect in real life is there when watching fireworks, without having any disturbance from the shadow or dark areas.

The flame colours of metal salts in fireworks

The most known colours of metal salts are barium with bright greens; strontium yields deep reds; copper produces blues and sodium yields yellow. Mixing elements can cause new colours like in strontium and sodium brilliant orange; titanium, zirconium, and magnesium silvery white. Copper and strontium make lavender. *(Flame Test Colors and Procedure (Chemistry), 2022)* These flame colours are not known in every day life. Watching them at a dark background (night sky) make them look magnificient. Humans perceive colours normally looking at pigments where light falls on or mixing lights.

Looking into the light source and fireworks

In normal life, people don't look into the light sources. Because it's mostly very bright and it can damage the eye itself. The exceptions are sun at sunrise and sunset, the moon and fire. They have all colours like white, red. orange and yellow. In the last decades of the computer age people look directly into the light at the screen for long periods of time. It has much more less illumination intensity then the conventional light sources. So fireworks are a special form of conventional light sources which are in different colours and changing shapes which last just for seconds.

Chiaroscuro and Fireworks

Chiaroscuro is used first in painting than in photography for describing the effect of colours to black or very dark areas in the visual field. This type of contrast was used by the painters for the first time in the Renaissance time. It was mostly used in the Baroque time. Some artists who used these techniques are Leonardo da Vinci, Caravaggio, Rembrandt, Vermeer and Goya. It produced very dramatic and impressive light effects. *(Correa-Herran et al, 2020 and Todd, 2020)* In chiaroscuro you mostly find five areas of illumination: Highlight, halftone, deep shadow, reflected light, and cast shadow. The most important parts are highlights of illumination and dark shadows.

Fireworks are fired mostly in dark nights to achieve deep black background so the colours of the firework have a big contrast to the background. So most of the humans enjoy the fireworks as a show on the black background which doesn't have normally any colours or any changes over night.

Attempts to simulate fireworks displays digitally

Wang et al (2021) worked about the imaging the colors of fireworks in 3D colorful displays. Even today, it's not easy to create "optical fireworks" with the use of nanotechnology and nanooptics. Their 3D printed optical fireworks security labels introduce applications for optical elements integrated with nanostructures in 3D colorful displays and anticounterfeiting labels.

Conclusions

Fireworks have an unique place in human visual perception. Not only are lighting levels on the sky, but also the perception of dark backgrounds around fireworks without any HDR effect. So the contrast of colors to black background is a live chiaroscuro effect, which cannot be perceived normally. So the colours of fireworks are perceived vividly.

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4. Color and Physiology

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Modern board games and color blindness: exploring accessibility challenges

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Abstract

There has been a significant resurgence of interest in the board game industry, with approximately 4000 new board games being created and distributed worldwide annually in recent years. While there is increasing gender balance among board game players, men currently make up a slight majority. As a result, it can be estimated that about 10% of board game players have some form of color deficiency. However, there is still a gap in addressing this issue compared to other industries, such as computer games. Although there is growing awareness in the board game design community, this paper explores the current use of color in board game design and the state of color accessibility in the board game publishing industry.

Keywords: Color Blindness, Boardgames, Accessibility

Introduction

The board game industry is a highly thriving and professional sector, that it is experiencing a strong acceleration in terms of revenue, number of professionals involved, and number of new games produced and distributed. Colorblind individuals constitute a significant portion of potential board game buyers. How do board game publishers approach this issue? This work aims to present some findings from a study that sought to investigate this problem among the most prominent European publishers.

Before addressing this topic, we want to briefly introduce some less-explored aspects of color blindness. The conventional notion of the human color vision process often draws parallels with that of a color camera. This analogy suggests the presence of color sensors at individual "points," generating color sensation at those points. In reality, the process of color vision is far more intricate, encompassing not only signal transduction within the retina but also a pivotal phase of spatial signal processing. This secondary stage holds paramount importance in making our vision robust to the complex changes of the world around us, featuring vital adaptive mechanisms such as color constancy [1]. Another noteworthy function of spatial processing within vision involves the restoration of signal dynamics lost on the retina, due to the effects of ocular glare [2].

The spatial component of vision has been acknowledged and established since the 1950s [3-7]. However, this important stage is frequently overlooked in numerous research domains pertaining to color, color deficiency being a prominent example. A Color Deficient Observer (CDO) experiences an anomaly in the response of a specific type of cones, yet retains the same structural foundation as the visual system, inclusive of the spatial processing component. The influence of spatial visual processing on the ultimate perception of color for a CDO is a relatively recent area of exploration [8], one that holds considerable fascination for us. These notes aim at introducing that, since CDOs have the same spatial properties of vision as normal observers, it is sensible to assume that as well they have spatial compensatory mechanisms. It may turn out that for CDOs the final color appearance of an area may differ from the color of the stimulus coming from that area. And this cannot be estimated only from the color signal at the point.

Color plays very often a major role in board game design and mechanics; this means that considering CDOs is a mandatory point to address in the design phase to make an accessible boardgames. That being said, how do boardgame editors face the design for Color Deficient Observers into the rapidly expanding board game market? [9]

The publisher's situation

Color is a fundamental part of the game interface and provides various information such as whether a piece belongs to a player or a faction or to identify game resources. This means that considering CDOs within your gaming target can be fundamental not only to increase accessibility, but also to improve the perception of the game within the community.

As part of our study, we decided to expand the survey carried out with Italian publishers by trying to contact international publishers and especially by addressing central European publishers (Germany, France, Belgium, etc.) in order to investigate the perception of the problem in the states where the board game is more widespread and where the market is large. 22 publishing houses responded, providing extremely interesting results.

The first question of the survey tries to better understand the knowledge of color blindness by the publishers. The answers are shown in Fig 1, only 40.9% of the interviewees know that color blindness affects about 9% of the male population. This indicates that the knowledge of the problem is scarcely detailed.

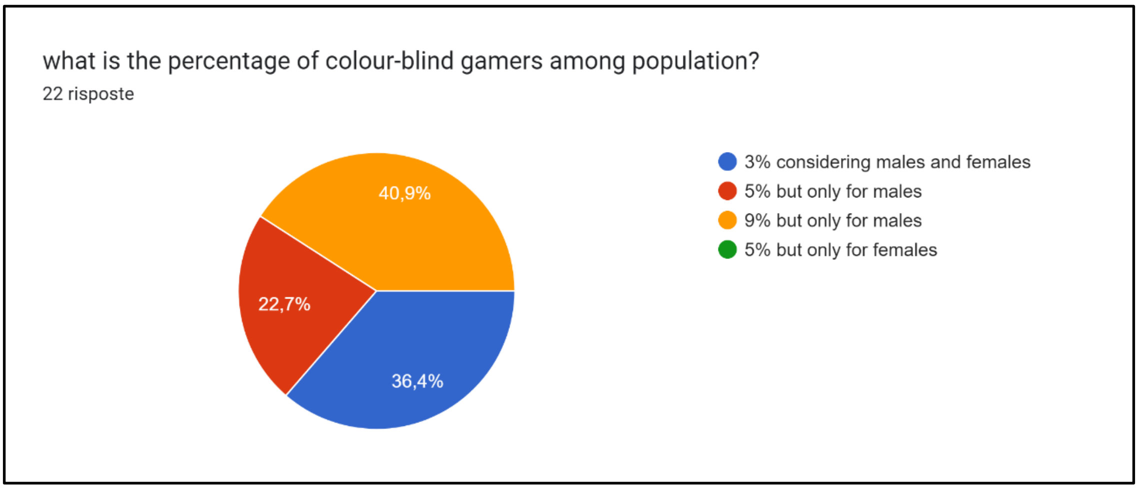

Figure 1. Knowledge about color blindness

However, it becomes interesting to see that 81.8% of publishers have already worked and published games with facilities or supports for CDOs (Fig.2), demonstrating that the problem is perceived as important even if there is no in-depth knowledge of it. This is probably related to the ever-increasing attention paid by publishers to minorities. Especially if read together with the results shown in Fig 3 where we understand that the request to develop games for CDOs is less than the answer.

We therefore tried to further investigate the motivations that lead a publisher to develop/produce games with support for CDOs and the motivations are as follows. 86.4% of the interviewees do it mainly to improve the accessibility of the game itself, without a specific need for economic return. Among these, 31.5% thinks there is a return to image and nothing more. One publisher only expects an increase in sales but less than 5%.

Then, we have asked what the company investment was to develop a game for CDOs. 90.9% attested it to be around €500 while the remaining 9.1% thought it was around €1000. No one thinks that this spending can reach or exceed €2,000.

It is also interesting to understand the size of these publishers, we measured it in two factors: the number of employees and the average circulation per game. In Fig 3 we see that 40.9% of companies have less than 5 employees, 45.5% of companies have between 5 and 15 employees. It follows that on average, board game companies are small. However, in the set of contacted companies there are between 15 and 50 employees and some with over 50 employees. The circulation of a game also greatly impacts the perception of costs. In Fig4 we note that only 9.1% have an average circulation of 1000 copies, 31.8% of publishers have an average circulation of 2000-5000 copies; 45.5% make a print run between 5,000 and 20,000 copies while 13.5% make a print run between 20,000 and 50,000 copies per game. We can therefore say that over half of the interviewees deal with making a "high" circulation and very few of the publishers interviewed have minimal editions.

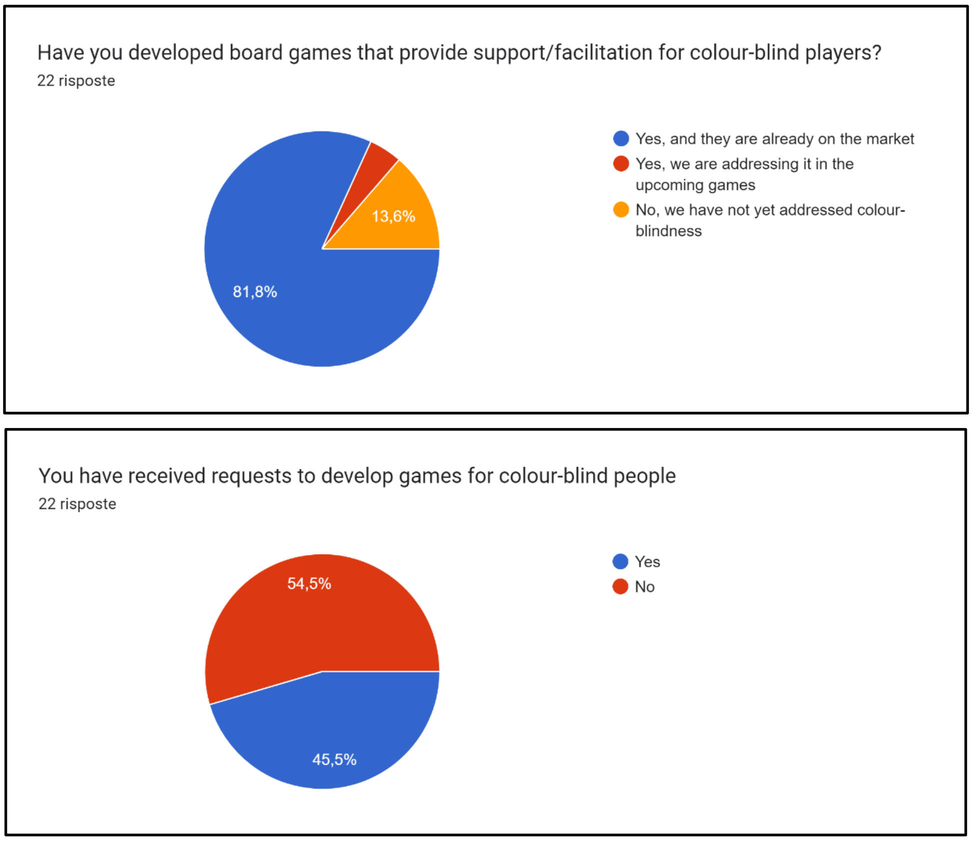

Figure 2. Game developing for color blindness

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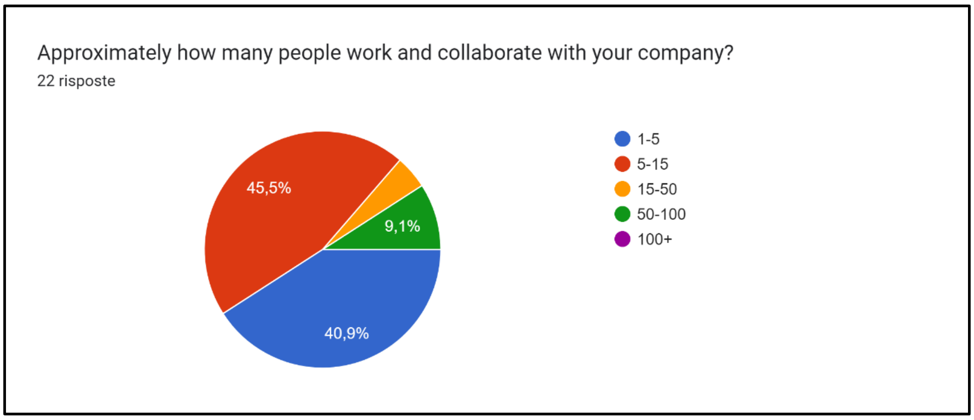

Figure 3. Number of employees

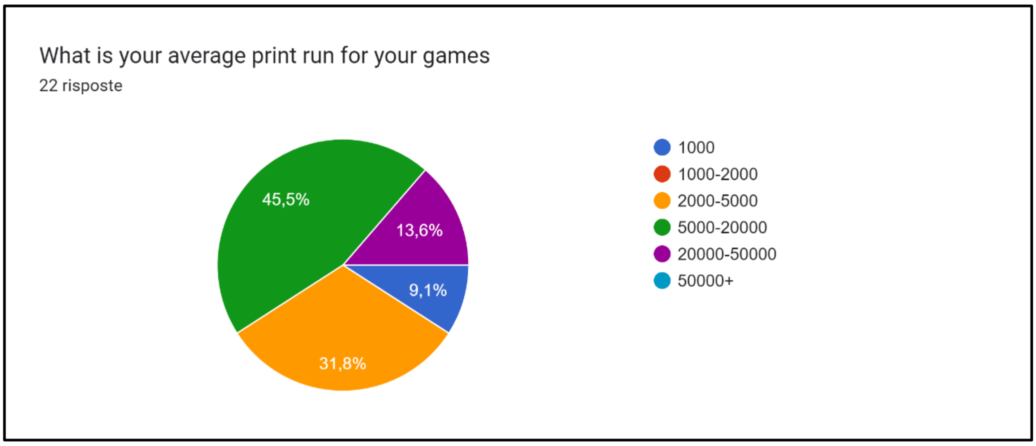

Figure 4. Average copies per game

Regarding the type of production, most of the publishers interviewed produce Family games (77.3%) and Eurogame (54.5%), while games for children are only 27.3% (see Fig 5).

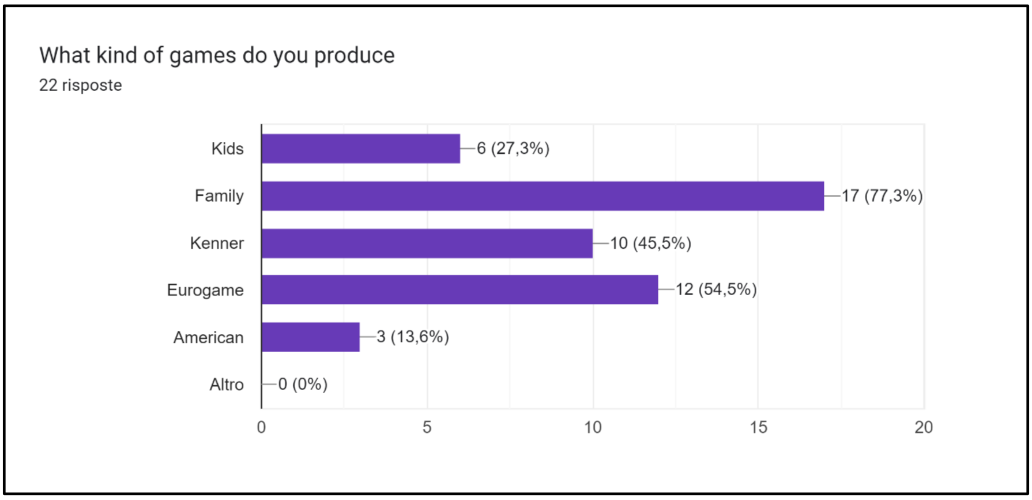

Figure 5. Game types

These data report the relation between the interviewed publishers and CDOs. But what strategies/tools do they use to get a product suitable for CDOs?

Thus, we have asked what strategies to deal with CDOs they use, and the results are shown in Tab1. Almost all publishers (86.4%) have chosen to associate a symbol to each color for player and/or resource in order to link the information to an alternative element that is easily recognizable by CDOs. While 54.5% also adopted a color-blind color palette.

Table 1: Strategies to deal with CDOs

Graphic symbols with each player/resource colour	86,4%
Colour-blind palette	54,5%
Graphics with colour-blind support tools	50%
Different forms to the game resources	45,5%
Test with a group of colour-blind players	27,3%
others	4,5%

Unfortunately, only 27.3% of publishers used tester CDOs to validate games. Fig 6 shows us the composition of the sample of testers used and Fig 7 the number of testers used by the same publisher.

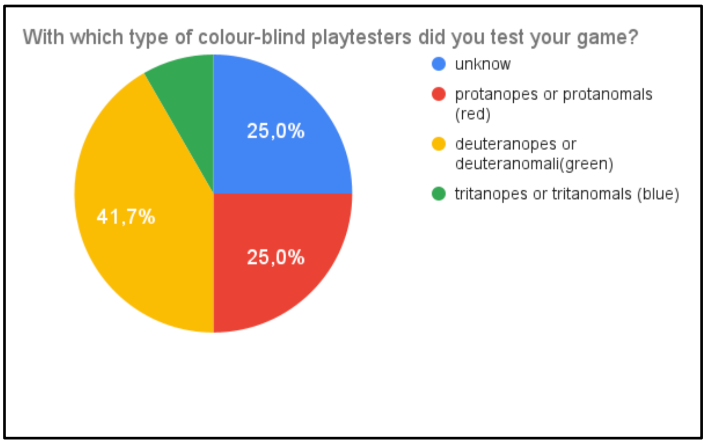

Figure 6. Game tester types

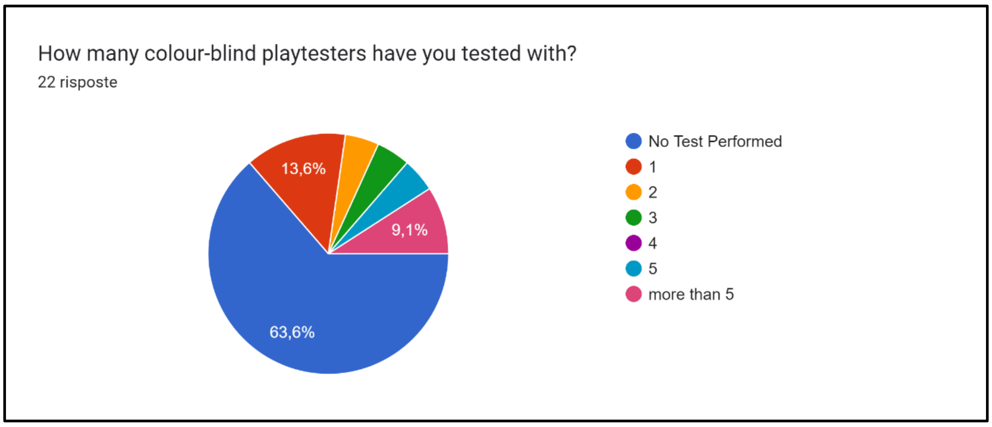

Figure 7. Number of game tester

The use of a color palette for CDOs is far more complex than one might think because it is not easy to identify whether the chosen colors are easily distinguishable, and the choice of palette is not always appreciated by non-colorblind players. We then tried to understand, when used, how it was selected. The survey results are shown in Fig 8 where it can be seen that the internet is chosen by the majority. However, this approach has a risk, a downloaded palette needs to be tested before its use. Although typically such a choice is better than no choice at all.

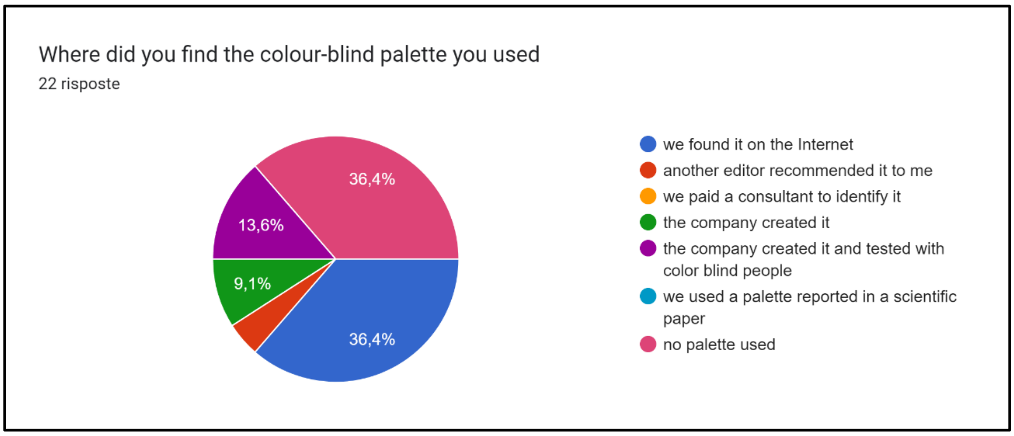

Figure 8. Source of CDOs palettes

We also asked at what stage in the process publishers start thinking about colorblind users. Fig 9 shows the results. Most respondents (63.6%) start to consider color blindness when starting to design graphics and choose materials. 22.7% start with the development of the game itself, or in the prototyping phase of it. A few, however, consider it near the end of its development.

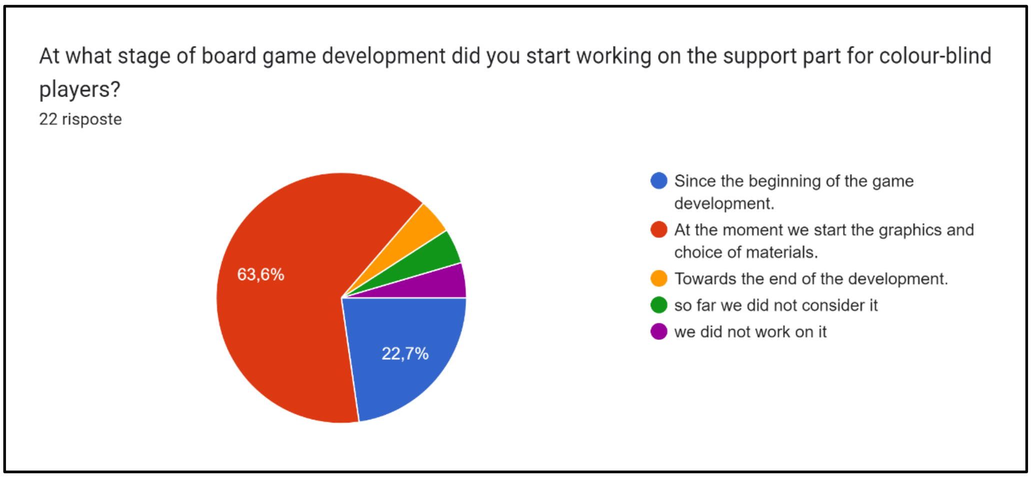

Figure 8. At what stage are CDOs considered

Conclusions

Given the rapid growth of the board game market over the last 30 years and the fundamental role of graphics, illustrations, and the use of color within this type of product, it is natural that the market has begun to consider how to comply CDOs needs. The data here report show how the publishers interviewed have in some way moved to make their products suitable for color blind customers.

However, each publisher is moving in its own way without a standard or common practice having been defined. This is certainly an indication of the absence of organic research work on this issue as has instead been done in the field of video games.

It emerges the need to define a set of practices and tools for publishers that they can use during the development of their products to find specific solutions and make their products accessible to CDOs. This shall result in further research on this topic and a wider dissemination of the results in the field of boardgame professionals.

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Modern boardgames: a colorimetric analysis from the point of view of color deficiencies

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Abstract

Color vision deficiency is a condition that impairs one's ability to see color or distinguish between different colors. In Europe, around 8.8% of the male population and 0.4% of the female population are color deficient. When playing tabletop games or board games, color blindness can prevent players from distinguishing between different game elements, leading to a reduced enjoyable gaming experience.

Color serves two purposes in board games: aesthetic and gameplay. The gameplay aspect is more critical as different colors are typically used to differentiate among game elements with different meanings or belonging to different players. While it is important for a color deficient player to fully enjoy the aesthetics design of the game, their difficulties to play the game can render it useless. Some games on the market are difficult or almost impossible for color deficient people to play, forcing them to come up with homemade solutions to play the game.

This study aims to explore the use of color in various board games by measuring the reflectance spectra of the many colored components of the game, such as board areas, cards, pieces, and other game resources. The spectra are acquired using a spectroradiometer and are then used to calculate the CIE xyY coordinates to determine whether the colors of each game fall or not on the daltonic confusion lines in the CIE chromaticity diagram. This paper presents the preliminary results of this investigation.

Keywords: Color blindness, color deficiency, board games.

Introduction

In recent times, there has been a growing emphasis on accessibility across a lot of different fields, and one of these fields is about color vision deficiency in board games.
Color vision deficiency, commonly known as color blindness, affects approximately 8.8% of the male population and only 0.4% of the female population (Birch, 2012; Hunt and Carvalho, 2016) and is the inability to distinguish certain shades of color. This condition is due to the fact that human color vision relies on the response of three classes of photoreceptors of the retina known as *cones* and sensitive to photons of varying wavelengths, corresponding to the long-wavelength (L), middle-wavelength (M), and short-wavelength (S) regions of the visible spectrum. Color vision deficiency typically results from either a complete absence of one of the three classes of cone pigments or alterations to one of them (Melillo *et al.*, 2017).
When discussing accessibility for individuals with color vision deficiency, it's important to note that many board games, both older and newer, have not been designed with color blindness in mind. This oversight often forces individuals with color vision deficiency to devise their own methods to enjoy these games. For instance, two tokens with the same shape but different colors may appear identical to a colorblind user, significantly impacting his gaming experience.

The use of colors in board games differs a lot from game to game, serving both aesthetic and gameplay-oriented purposes. Even though it is essential for a colorblind player to appreciate the game's aesthetic design too, the challenges in playing the game can render it unenjoyable or impractical. Thus, in this research we studied the use of color in various board games focusing on gameplay characterization rather than the aesthetic. In particular, for each board game, we compared the colors of different components of the game (i.e., board areas, cards, paws, dice and other game resources) with the aim to identify board games that might pose challenges for colorblind users.

Among the different types of color blindness (i.e. *Monochromacy*, *Dichromacy* and *Anomalous Trichromacy*), the preliminary results of our research are focused on *dichromacy*, the most studied Color Vision Deficiency that includes *protanopes*, *deuteranopes* and *tritanopes* individuals. *Protanopia* (also known as *red Dichromacy*) is caused by the lack of the L cone, resulting in an inability to differentiate colors within the red spectrum, and in difficulty distinguishing between red, yellow, and orange hues. *Deuteranopia* (also referred to as *green Dichromacy*), attributed to the absence of the M cone, is characterized by a reduced sensitivity to green which causes deuteranopes to struggle to differentiate between colors in the red, yellow, and green regions of the spectrum. Finally, *Tritanopia* (also known as *blue Dichromacy*), linked to the absence of the S cone, involves a loss of sensitivity to blue, leading to an inability to distinguish between blue and yellow hues.

This paper shows the preliminary result of this analysis.

Board Game Selection

For this study, we analyzed the board games listed in Table 1. In the list, a couple of recurrent names of designers and artists are present. Among the designers, there are Emerson Matsuuchi, author of the *Century* series and Uwe Rosenberg for *Agricola* and *Seconda Chance*. Among the artists, there are Chris Quilliams, responsible for the *Century* series, *Beez* and *Blackout Hong Kong* and Klemens Franz for *Grand austria hotel* and *Agricola*.

The selection criteria behind the chosen games are twofold. Firstly, we received recommendations from colorblind individuals who enjoy playing board games and have encountered difficulties with some of the games on our list. As an example, the game *Earth* presents a notable challenge for individuals with color vision deficiency due to the presence of numerous distinct game pieces, many of which are various shades of green, a color that poses difficulties for many dichromats.

Secondly, the choice was influenced by the availability of these games in the market, including both well-known titles and more recent or lesser-known ones.

Board Game Analysis

For each game, we had to make decisions regarding what to measure and what to exclude from the analysis. We focused on the game elements whose color is necessary for the gameplay. To organize the analysis, we divided the different game components into four distinct categories: *Pawns* (all game pieces used to represent a player or the resources that a player can acquire) *Cards*, *Dices* and *Boards*. Each category can have a further subdivision based on the shape of the object or its function in the gameplay. For example, *pawns* can be divided for their shape and usage (such as hexagon or circle objects in *Brass Birmingham*) or for what they represent (such as resources or player tokens), *dice* can be differentiated for the number of faces, *cards* from the layout of the single card, etc.

As a result of this categorization, for each game, we created groups of elements with the same shape, aspect, and function but different colors. At this point, it is clear that for the discernment of these components, color plays a crucial role in gameplay. Therefore, given the importance of color discrimination, we conducted comparisons of these colors within each subcategory to explore whether discrimination is still possible also for dichromat players.

Table 1. - List of the board games with authors and artists (*BoardGameGeek*, 2023). Some titles are not in English since we kept the language title based on the local version available.

Game	Authors / Designers	Artists
Brass birmingham	Gavan Brawn, Matt Tolman, Martin Wallace	Gavan Brawn, Lina Cossette, David Forest, Damien Mammoliti, Matt Tolman
Kamisado	Peter Burley	Peter Burley, Peter Dennis, Steve Tolley, Yoojung Lee
Grand austria hotel	Virginio Gigli, Simone Luciani	Klemens Franz
Beez	Dan Halstad	Chris Quilliams
Zanzibar	Franz-Benno Delonge	Claus Stephan, Mirko Suzuki
Carcassonne	Kalus-Jürgen Wrede	Marcel Gröber
Bitoku	Germàn P. Millan	Edu Valls
Coatl	Pascale Brassard, Etienne Dubois-Roy	SillyJellie
Century– Eastern Wonders	Emerson Matsuuchi	Atha Kanaani, Chris Quilliams
Bonfire	Stefan Feld	Dennis Lohausen
Agricola	Uwe Rosenberg	Klemens Franz
Blackout Hong Kong	Alexander Pfister	Chris Quilliams
Euphoria	Jamey Stegmaier, Alan Stone	Jacqui Davis
Calico	Kevin Russ	Beth Sobel
Chakra	Luka Krleža	Claire Conan
It's a wonderful world	Frédéric Guérard	Anthony Wolff
Tajuto	Reiner Knizia	Maxence Burgel, Damien Colboc
Hanabi	Antoine Bauza, Gérald Guerlais	Antoine Bauza, Gérald Guerlais
I colori delle emozioni	Josep M. Allué, Dani Gòmez	Anna Llenas
Tentacolor	Davide Panizza	Cécil Le Brun
Seconda Chance	Uwe Rosenberg	Justine Nortjè, Max Prentis
Colorfox	Martin Nedergaard Andersen	Katie Burk
Mandala Stones	Filip Głowacz	Zbigniew Umgelter
Atlantis Rising	Galen Ciscell	Vincent Dutrait
Florenza dice game	Danilo Festa, Stefano Groppi	Ivan Zoni
Clever Hoch Drei	Wolfgang Warsch	Leon Schiffer
Earth	Maxime Tardif	M81 Studio, Conor McGoey, Yulia Sozonik, Kenneth Spond
SerpentinGiro	Katrin Abfalter	Irinia Pechenkina
Century - la via delle spezie	Emerson Matsuuchi	Chris Quilliams, David Richards, Fernanda Suàrez
Schonbrunn	Tommaso Bagnoli	Francesco Mattioli, Maichol Quinto

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We acquired the reflectance spectra of each different colored object for each subcategory. For this purpose, we used the portable spectrophotometer CM-2600d by Konica Minolta that inspects a circle area of 3 mm in diameter. The instrument was calibrated by measuring the supplied white calibration plate as a reference for white and a shaded area as a reference for black. Through the auto-average parameter, each spectrum was obtained as an average of three consecutive measurements. The spectra were acquired considering the UV component and in SCE (Specular Component Excluded) mode, which subtracts the specular component of the light source from the sample when calculating the amount of reflected light. The spectra obtained ranged from 360 nm to 740 nm with a sample step of 10 nm.
For each colored element, we typically acquire a single reading. However, in certain exceptional cases involving transparent or semi-transparent tokens, it was necessary to sample color readings twice, capturing data from different points on the piece to ensure a more comprehensive and accurate acquisition of the color.

Starting from the obtained spectra, we then calculated the XYZ and xyY coordinates of each sample using the *colour-science* package of Python (Colour Developers, 2015). In particular, the coordinates were calculated using D65 as the illuminant and the CIE 1931 (2°) observer as the standard observer following the CIE guidelines in (CIE TC 1-85, 2018). For each subcategory of colored object, we plotted the colors to be discriminated on the 1931 CIE Chromaticity Diagram along with the various confusion lines for the three different types of dichromats, that originated from the confusion points specified in the book (Wyszecki and Stiles, 2000): the xy coordinates for *protanope*, *deuteranope* and *tritanope* individuals are respectively (0.747, 0.253), (1.080, -0.080) and (0.171, 0.000).
Since all the colors along a confusion line are perceived as identical by a color-blind person, plotting all the colors used in a particular subcategory can allow us to discern which pairs of colors could be confused by a dichromat.

Results and discussions

Figure 1 shows an example of the result computed for the subcategory of dice in the board game *Florenza Dice game*, in which the discrimination of the color of the dices is necessary for the different uses in the various phases of the game.

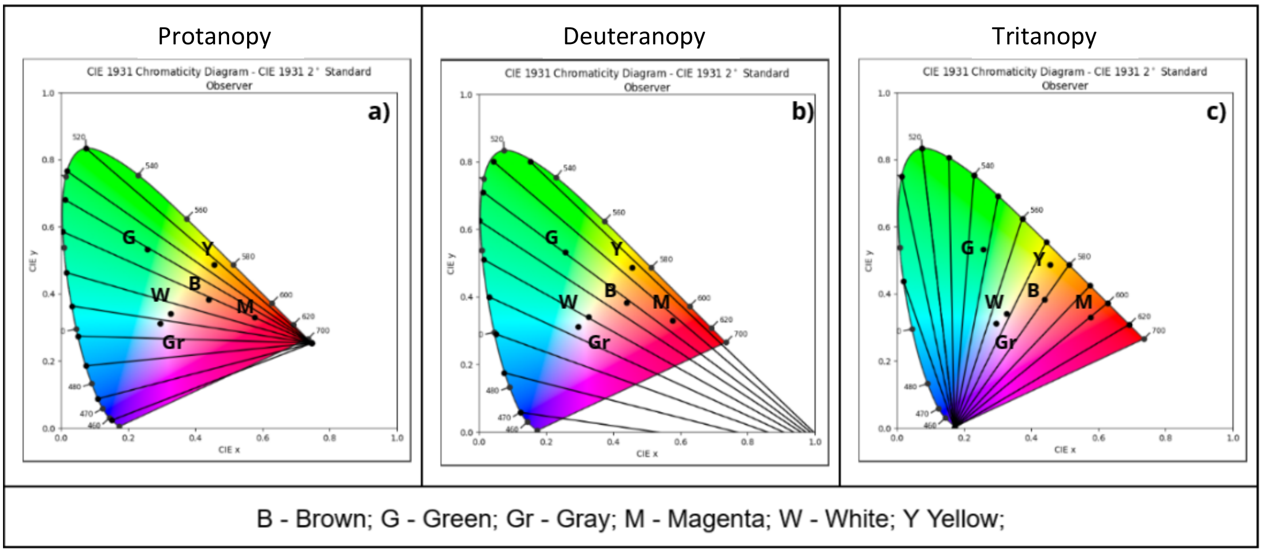

Figure 1. - Chromaticity Diagram and Confusion lines for Protanopy (a),Deuteranopy (b) and Tritanopy (c) for the *dice* category in the game *Florenza dice game.*

From the chromaticity diagrams, red and brown could be challenging to discriminate for protanope players, brown and green for the deuteron individuals, while no problems should arise for Tritan users.
In Table 2 all the results for each subcategory of every game under analysis are summarized. In particular, along with the description of the subcategory (type, element, and number of colors), it can be seen the pairs or triplets of colors that can be respectively confused by protanope, deuteranope and tritanope individuals.

Table 2. - Results of the analysis. Every row represents a subcategory of the analysed game.

Game	Type	Element	Number of colors	Colors that can be confused		
				Protanope	Deuteranope	Tritanope
Brass Birmingham	Pawns	Resources	4	-	-	Yellow-Purple
	Pawns	Circles	4	-	-	Yellow-Purple
	Pawns	Hexagons	4	-	-	Yellow-Purple
	Pawns	Cubes	2	-	-	-
Kamisado	Board	Squares	8	Brown-Green	Purple-Blu, Brown-Green	Blu-Green, Yellow-Brown
	Board	Writings	8	Red-Green, Purple-Blu, Brown-Orange	Red-Brown-Orange	Green-Blu, Purple-Yellow, Red-Brown-Orange
Grand Austrian Hotel	Pawns	Circles	5	Purple-Light Blu	-	-
	Pawns	Cubes	4	-	-	-
Beez	Pawns	Big Circles	5	-	Purple-Light Blu, Red-Yellow	-
	Pawns	Small Circles	5	Red-Yellow	Purple-Light Blu, Red-Yellow	-
	Pawns	Hexagon	4	Cyan-White	-	-
Zanzibar	Pawns	Mercants	5	Orange-Yellow	Orange-Yellow, Red-Green	-
	Pawns	Scorekeeper	5	Orange-Yellow	Orange-Yellow, Red-Green	-
Carcassone	Pawns	Humans	5	-	Red-Green	-
Coatl	Pawns	Heads	5	-	-	-
Bitoku	Pawns	Onigiri	4	Green-Brown	Green-Brown	-
	Pawns	Animals	4	Green-Brown	Green-Brown	-
	Pawns	Samurai	4	-	-	-
	Pawns	Fish	4	Green-Brown	Green-Brown	-
Century – Eastern Wonders	Pawns	Cubes	4	Red-Brown	Red-Green	-
	Pawns	Houses	4	Light Blu - Pink	-	-
Bonfire	Pawns	Angels	8	Red-Wood, Cyan-Pink, Green-Yellow	-	Gray-Wood
	Pawns	Humanoide	5	Green-Yellow	-	-
	Pawns	Circle	4	Green-Yellow	-	-
	Pawns	Resources	6	Pink-light Blu	Pink-Gray	Gray-Wood
Agricola	Pawns	Plank	4	Purple-Light Blu,	-	-
	Pawns	House	4	Purple-Light Blu,	-	-
	Pawns	Humanoide	4	Purple-Light Blu,	-	-
	Pawns	Animals	3	-	-	-
	Pawns	Resources	5	Orange-Yellow	-	Yellow-Brown-Wood

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Blackout: Hong kong	Pawns	Circles	4	Orange-Green	Orange-Green	-
	Pawns	Cubes	4	Orange-Green	Orange-Green	-
	Pawns	Houses	4	Orange-Green	Orange-Green	-
	Dice	D6	3	-	-	-
	Cards	cards	4	-	Red-Yellow	-
Euphoria	Pawns	Heart	6	-	Purple-Blu	-
	Pawns	Star	6	-	Purple-Blu	-
	Pawns	Head	6	-	Purple-Blu	-
	Pawns	Resources	7	Green-Yellow, Gray-light Blu	Gold-Yellow-Orange	Gold-Yellow-Green
	Dice	D6	6	-	Green-Red	-
Calico	Pawns	Tassel	6	Purple-Blu, Magenta-Light Blu	-	Purple-Yellow
	Pawns	Dense tassel	6	Light Blu-Magenta	-	Purple-Yellow
Chakra	Pawns	Circles	8	Yellow-Green, Red-Orange, Light Blu-Purple	Yellow-Green, Red-Orange, Light Blu-Purple	Purple-Yellow-Black
	Pawns	Gems	8	Green-Orange, Purple-Blu	Red-Green-Orange, Purple-Blu	Green-Blu
It's a wonderful world	Pawns	Resources	6	Red-Yellow	-	Gray-Yellow
	Cards	Cards	6	Yellow-Green	Yellow-Green-Orange	-
	Cards	Resources	8	-	Red-Green	-
Tajuto	Pawns	Pagodas	8	Pink-Blu	Red-Green	Blue-Green, Pink-Orange- Red
	Pawns	Cubes	8	Green-Orange	Red-Green	Pink-Orange
	Pawns	Humanoide	4	Green-Orange	-	Green-Blue
Hanabi	Pawns	Token	1	-	-	-
	Cards	Cards	6	Red-Green	-	Yellow-Black
I colori delle emozioni	Pawns	Tokens	5	-	-	-
Tentacolor	Pawns	Tentacles	6	Purple-Red	Orange-Green	Yellow-Orange
Seconda Chance	Cards	Cards	8	Green-Orange, Purple-Blue	Yellow-Orange	-
ColorFox	Pawns	Sticks	6	-	Red-Green	-
	Cards	cards	6	Yellow-Green	Yellow-Green	Pink-Yellow
Mandala Stones	Pawns	Pawns	5	Black-Pink	Purple-light Blue	Purple-Yellow
Atlantis Rising	Pawns	Pawns	9	Clay-Green	-	Purple-Grey-Silver
	Pawns	Gems	5	-	-	-
	Dice	Dices	1	-	-	-
Florenza Dice Game	Dice	Dice	6	Red-Brown	Green-Brown	-
Clever Hoch Drei	Dices	Dices	6	-	-	Brown-Yellow
Earth	Pawns	Trees	4	-	-	-
	Pawns	Resources	3	-	-	-
	Pawns	Tokens	2	Green-Brown	Green-Brown	Green-Brown
	Pawns	Leafs	4	Purple-Blue	-	-
	Cards	Cards	20	Orange-light Brown-Green, Brown-Teal	-	Blue-Green, Brown-Orange
SerpentinGiro	Pawns	Pieces	4	Green-Orange	-	-
	Dice	Dice	4	Pink-Blue, Orange-Green	-	-
Century – la	Pawns	Cubes	4	Red-Brown	-	-

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via delle spezie	Pawns	Coins	2	-	-	Gold-Silver
	Cards	Points	4	Red-Brown, Green-Yellow	Green-Yellow	-
	Cards	Mercants	5	-	-	Gray-Green
Schonbrunn	Pawns	Numbered	6	-	-	-
	Pawns	Gentlemen	6	-	-	-
	Pawns	Military	6	-	-	-
	Pawns	Circles	7	-	-	-

Conclusions

In this study, we investigate the use of color in different board games in the context of accessibility. We conduct a comparative analysis of colors across different subcategories of resources (being them pawn, card, dice, or boards elements) that can be differentiated only by color. Colors positioned along the confusion lines of the chromaticity diagram cannot be discriminated by protanope, deuteranope, and tritanope players. The preliminary results confirm that various games from different authors and artists may pose potential challenges for users with color vision deficiencies. This study lays the foundation for further investigations aimed at analyzing and developing the accessibility of board games.

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The Physiology and Management of Individual Differences in Color Vision

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Abstract

Color provides a means to coarsely discriminate surface spectral reflectance as well as the relative spectral content of light sources. Color is a synthetic product arising from the activation of a subset of our visual pathways. Consequently, individual differences in optical and neural physiology are likely to result in individual differences in color. Individual differences in "normal" color vision are well documented and the major underlying factors have largely been identified and include: variations in inert ocular pigments (lens and macular), photopigment spectra (genetically determined), photopigment optical density, and ratios of cone photoreceptor types. In addition, variations in retinal and cortical encoding have also been proposed but have not been well characterized. In spite of known individual differences in color vision, most applications of color reproduction assume a CIE "standard observer" for both underlying cone mechanisms or "fundamentals" and for the luminance dimension of color vision. Assuming an averaged or standard observer is, of course, convenient for color specification. However serious problems can arise in the context of metamerism (color matching and reproduction). The spectra from one scene (e.g. natural environments) usually differ greatly from that of a metameric match in a reproduction. Since the color match equations depend critically on the underlying fundamentals and luminosity, variation in these creates different matches. This problem is actually enhanced for some modern color reproduction that employs narrow band "primaries". Several approaches have been proposed to address the problem of individual differences and develop "personalized" color spaces for more accurate color reproduction. One approach is to characterize the individual's color space in the same way in which the "standard observer" was developed, by measuring full color matching and luminosity functions and ignoring physiology. Though logical, measurement of full color matching functions is technically difficult and time intensive. Another approach is to independently characterize the underlying physiological factors and employ a model to predict individual color vision. Unfortunately, this approach is even more technically and temporally demanding.
A third approach is to take advantage of the fact that the same factors that most affect the color fundamentals, also affect luminosity. Unlike the tedious process of using complete color matching functions to derive the fundamentals, measurements of relative luminosity are easily obtained through convenient and rapid psychophysical techniques. Measurements of individual differences in luminosity might therefor provide a convenient way to develop "personalized" color spaces for color reproduction. Another hybrid approach combines a limited number of color matches with measures of luminosity. Here we present modeling and behavioral data to evaluate these approaches.

Keywords: color vision, hybrid approach, physiology.

Background

Color provides a means to coarsely discriminate surface spectral reflectance as well as the relative spectral content of light sources. Color is a synthetic product arising from the activation of a subset of our visual pathways. Consequently, individual differences in optical and neural physiology are likely to result in individual differences in color. Individual differences in "normal" color vision are well documented and the major underlying factors have largely been identified and include: variations in inert ocular pigments (lens and macular), photopigment spectra (genetically determined), photopigment optical density, and ratios of cone photoreceptor types. In addition, variations in retinal and cortical encoding have also been proposed but have not been well characterized. In spite of known individual differences in color vision, most applications of color reproduction assume a CIE "standard observer" for both underlying cone mechanisms or "fundamentals" and for the luminance dimension of color vision. Assuming an averaged or standard observer is, of course, convenient for color specification. However serious problems can arise in the context of metamerism (color matching and reproduction). The spectra from one scene (e.g. natural environments) usually differ greatly from that of a metameric match in a reproduction. Since the color match equations depend critically on the underlying fundamentals and luminosity, variation in these creates different matches. This problem is actually enhanced for some modern color reproduction that employs narrow band "primaries". Several approaches have been proposed to address the problem of individual differences and develop "personalized" color spaces for more accurate color reproduction. One approach is to characterize the individual's color space in the same way in which the "standard observer" was developed, by measuring full color matching and luminosity functions without physiological assumptions. Though logical, measurement of full color matching functions is technically difficult and time intensive. Another approach is to independently characterize the underlying physiological factors and employ a model to predict individual color vision. Unfortunately, this approach is even more technically and temporally demanding. A third approach is to take advantage of the fact that the same factors that most affect the color fundamentals, also affect luminosity. Unlike the tedious process of using complete color matching functions to derive the fundamentals, measurements of relative luminosity are easily obtained through convenient and rapid psychophysical techniques. Measurements of individual differences in luminosity might therefor provide a convenient way to develop "personalized" color spaces for color reproduction. Another hybrid approach combines a limited number of color matches with measures of luminosity. Here we present modeling and behavioral data to evaluate these approaches.

Methods

To estimate the tilt of individual equiluminant planes, we performed minimum motion tasks using chromatic grating modulated along the L-M and S cone isolating axes in a 3-dimensional color space. To estimate the direction of individual opponent axes (and thus the individual differences in fundamental) we performed a chromatic threshold discrimination task in the presence of chromatic adaptation [1,2]. Predictions were also generated for 100 simulated subjects using random values of the sources of sensitivity variation based on reported distributions [4].

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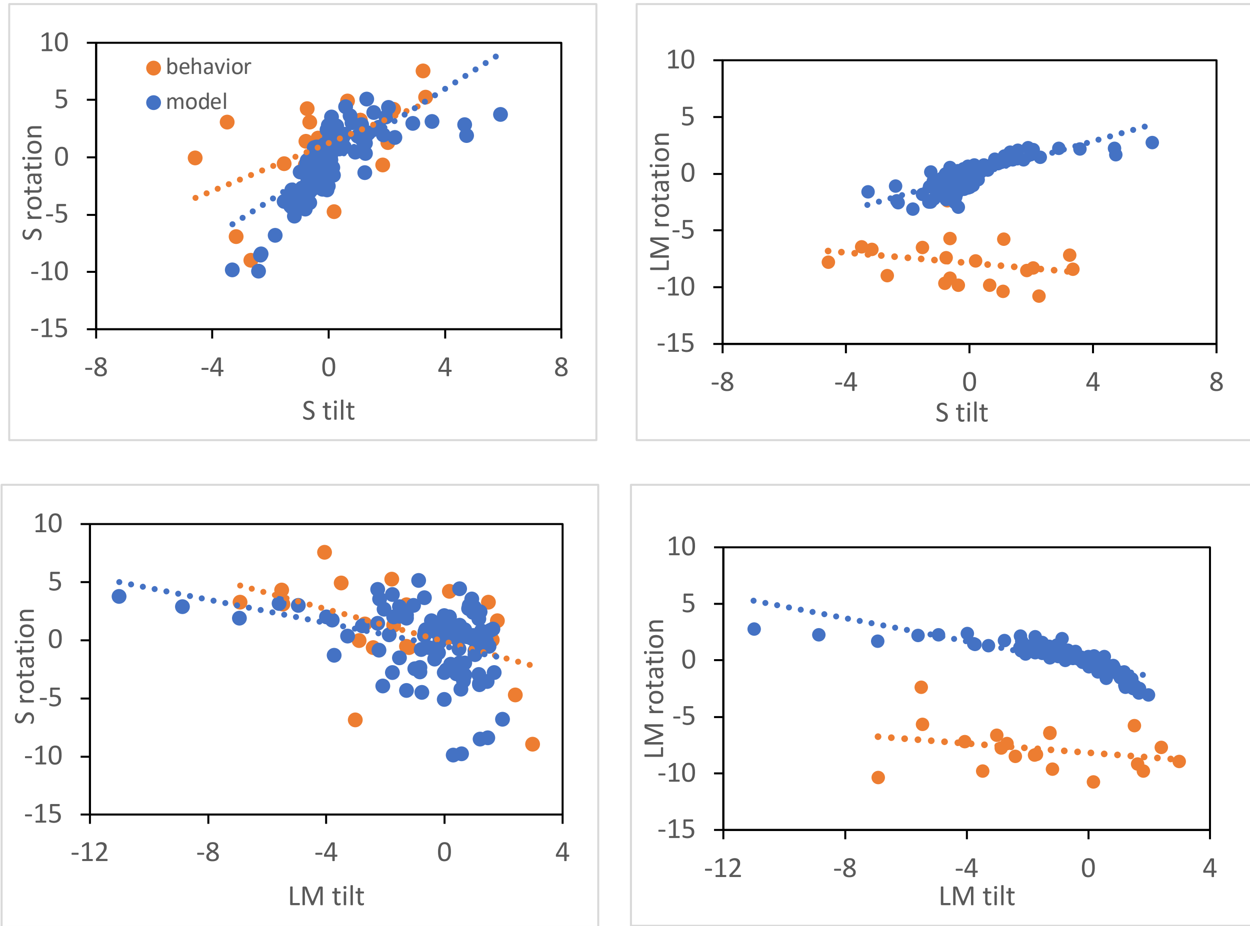

Fig. 1 - Correlations between equiluminance settings and axes rotation. Model (blue) and Behavioral (data) are both plotted

The results shown in Figure 1 suggest that the behavior does not perform as well as the model predicts. For the behavior, the S axis equiluminance settings in part predict the rotation of the S cone axes but not the LM rotation. LM axis equiluminance moderately correlates with S axis rotation but not for LM rotation.

Table 1 gives the correlation results for these predictions. Since both the S and LM equiluminance settings are used to define an individual's equiluminance plane, the table also includes multiple-correlation results wherein the information for both the S and LM axis equiluminance is used to predict rotations. This model improves the correlations for both the model and behavior as expected.

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R^2 Model

	S tilt	L-M tilt	S angle
L-M tilt	0.742126		
S angle	0.545344	0.122706	
L-M angle	0.641481	0.664696	0.301732

R^2 Behavior

	S tilt	L-M tilt	S angle
L-M Tilt	0.008029		
S angle	0.311662	0.219217	
L-M angle	0.065495	0.081444	0.00583

Mulitple Correlation (Model)

Adjusted R^2 (combined L-M and S tilt)

	S + L-M tilt
S angle	0.859427
L-M angle	0.696245

Multiple correlation (Behavior)

Adjusted R^2 (combined L-M and S tilt)

	S + L-M tilt
S angle	0.477398
L-M angle	0.14403

Table 1. Single and multiple correlation matrices for the data in Figure 1.

Conclusions

The relatively poor behavioral correlations may in part be explained by the difficulty in estimating the opponent axes. These data showed considerable variability within subjects and the task was difficult for some subjects. Full color matching functions may be needed to more accurately characterize the opponent axes to test the model more accurately. Nonetheless, the addition of a small number of color matches in spectral regions chosen to be sensitive to different sources of variability as has been applied to camera calibration[5], added to the two equiluminant estimations may greatly improve the feasibility of rapid characterization of individual color spaces.

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Using commercial glasses for CVD correction with digital displays

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Abstract

The development and commercialization of aids for improving, and sometimes allegedly correcting, the discrimination of colors, in color vision deficient subjects, has increased in the last few years. Producers often claim such devices are also effective in improving the experience of color vision while using digital displays, sometimes even selling specific types intended for indoor and display monitor usage. In general, the underlying mechanism of these physical ocular filters is to reduce the amount of spectral energy in specific bands of the visible spectrum. The most common digital displays rely on the emission of three light sources limited in band occupancy, so different filter types might be more or less effective when used with digital displays rather than when observing real scenes or pigments. This paper aims to comment and evaluate the effectiveness of such filters when used with different types of digital display technologies. We discuss whether inter-device variations (namely different gamuts) might alter the chromatic sensation of users.

Keywords: color deficiency, color blindness, color perception.

Introduction

The most common forms of congenital color blindness arise from a lack of a class of cones or an alteration in one of them, resulting in overlapping the spectral responses of two sets of cones (Birch, 2012; Hunt and Carvalho, 2016). The most common form is the latter and takes the name of anomalous trichromacy, a condition in which the L (protanomaly) or the M (deuteranomaly) cones exhibit a slightly altered spectral response, resulting in the two curves getting closer and thus reducing the delta between the signals produced by the two sets of cones for a given stimulus. This leads to a reduction of chromatic contrast between the L and M signals, leading to an under-stimulation of the neural pathway comprising the "red-green" opponent system (Boehm, A.E. *et al.*, 2021). In this study, we considered two glasses of two types manufactured by Pilestone and Enchroma. To make a preliminary assessment of the differences between glasses, after estimating the spectral sensitivities of the cones for an ideal protanomalous and an ideal deuteranomalous observer, we computed:

(a) The difference between the two sets of cones using both the actual spectral sensitivities;
(b) The spectral sensitivities weighted by the transmittance of the glasses' lenses;
(c) The filtering of the primaries of digital displays through the glasses lenses.

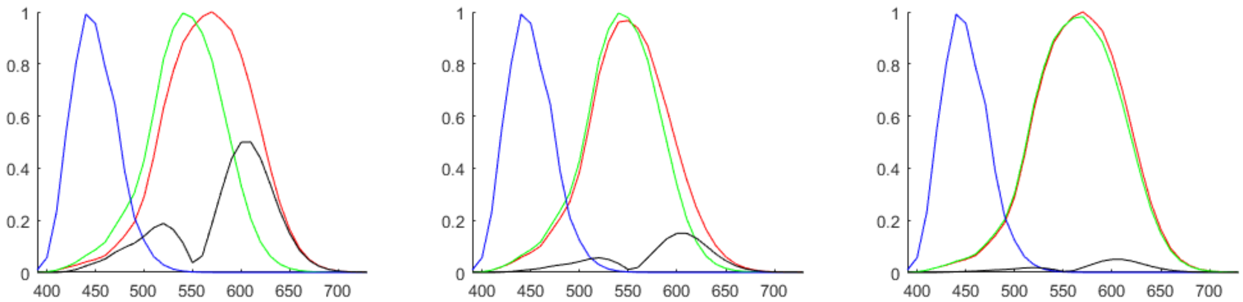
The pointwise absolute difference between the two spectra (L and M) can be interpreted as the resulting differential value generated by the two sets of cones for a monochromatic stimulus having unitary amplitude at different wavelengths. On the other hand, the delta between the filtered versions of the cones' response indicates the glasses' effectiveness in improving the separation between the signals generated by two cones for a given monochromatic stimuli. This separation can be compared with the L and M separations of the standard color observer, providing a preliminary idea of the glasses' effectiveness. In addition to these measures, the simulation of the filtering of the RGB primaries of a digital display can provide a preliminary assessment of the effectiveness of using glasses with digital displays.

Materials and methods

Cones spectral sensitivity estimation

As described in the Introduction, to assess the differences between the distinct types of glasses, we first computed an estimate of the spectral sensitivities of the cones for an ideal protanomalous and an ideal deuteranomalous observer. Later, we computed the difference between the two sets of cones using both the actual spectral sensitivities (as can be seen in Fig. 1) and the spectral sensitivities weighted by the transmittance of the glasses' lenses (Fig.2 and Fig. 3). The black plot in Fig. 1 shows the pointwise absolute difference between the two spectral sensitivities. The spectral sensitivities for the anomalous observers (L' and M') have been computed with a linear combination of both the L and M cones, based on the equation in Eq. 1 (Lucassen M. and Alferdinck J., 2006; Martínez-Domingo, M.Á., *et al.*, 2020):

$$L' = ((1 - d) \cdot L) + (d \cdot M)$$
$$M' = ((1 - d) \cdot M) + (d \cdot L)$$



Glasses transmittance measurement

The glasses that have been considered were manufactured by Pilestone and Enchroma, specifically, we had been supplied with four types of glasses from Pilestone and had acquired one type from Enchroma. All the glasses have had their transmittance computed by means of averaging the respective transmittances of each of the two lenses, which were measured using an A illuminant as a light source and an X-Rite Eye-One Pro spectrophotometer using the open-source software i1Toolz. i1Toolz is an open-source software currently under development that enables commercial spectrophotometers and colorimeters, usually destined for displays and printers' calibration and profiling, to take spectral measurements. Being the X-Rite Eye-One a spectrophotometer capable of only taking 45/0 reflectance or emission readings, using it to measure transmittance requires the use of an external light source against which the instrument, together with the software, needs to be calibrated (hence why a light source has been specified). The use of a type-A illuminant is a result of the fact that LEDs mimicking D65 or D50 light sources emit a relevant amount of energy in the blue region of the visible spectrum, which we noticed introduced errors in the longer wavelengths portion of the spectrum in the form of a transmittance even greater than 1 for some LEDs; emission measurements of the lenses illuminated on the side opposing the instrument with a blacklight showed that all of them undergo fluorescence when struck with short wavelengths of light, this is the reason why we chose to use an incandescent bulb to take all the measurements. The graph in Fig. 1 shows the spectral transmittances of the four glasses pairs made by Pilestone and the one made by Enchroma.

The graph in Fig. 2 shows the spectral transmittances of the four glasses pairs made by Pilestone and the one made by Enchroma. Pilestone's type E and D shows some common characteristics with type A and B. Pilestone type A (as well as type E) has an almost neutral density throughout the shorter to medium wavelengths, effectively emphasizing the longer wavelength above around 650 nm, resulting in a reddish color. Pilestone type B (as well as type D) shows a similar behavior, with

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a higher density in the medium wavelengths dropping below 480 nm. The Enchroma Cx3, on the other hand, shows some interesting differences: they still emphasize the red portion of the spectrum but also show two lows effectively acting as narrow notch filters centered at 490 nm and 580 nm.

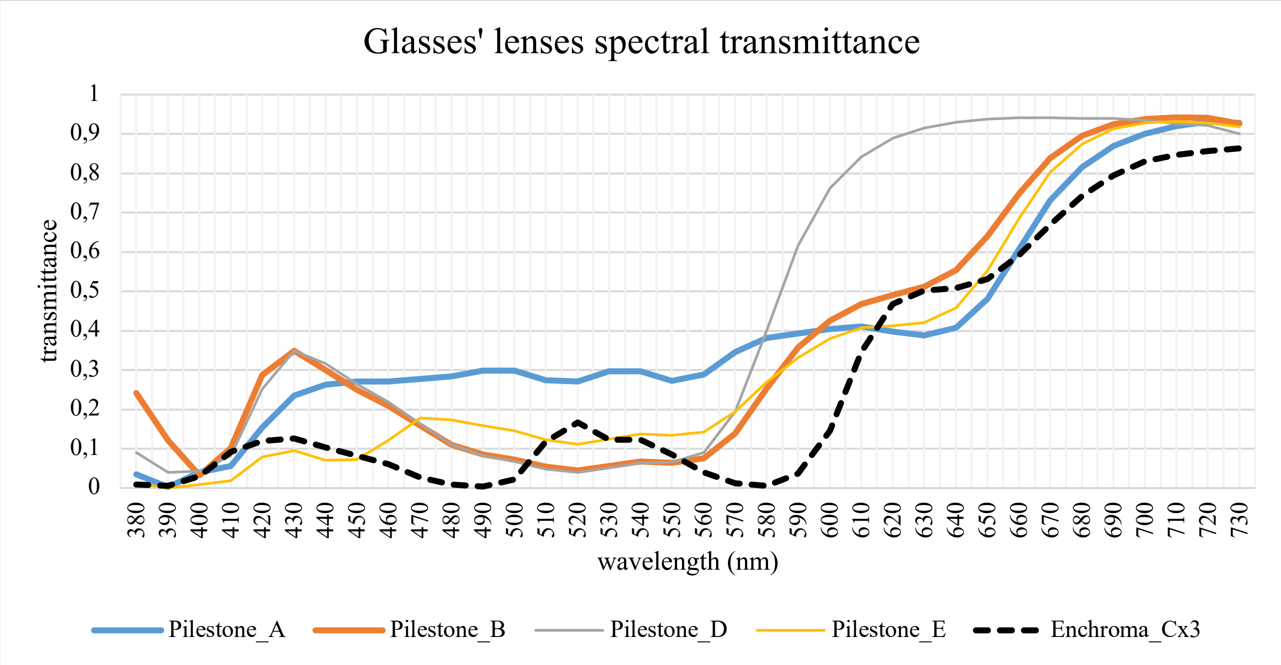

Fig. 2 – Spectral transmittances of the glasses' lenses. To make the graph easier to read, only some of the lenses have been highlighted, which are the ones on which the focus has been posed.

In Table 1, we report the average optical densities of the glasses in different portions of the visible spectrum (derived from Fig. 2). Optical density corresponds to the log_{10} of the reciprocal of the transmittance, so provide information on the average amount of light, which is filtered by the glasses, in three different regions of the visible spectrum, confirming the evaluations made to Fig. 2.

	Pilestone_A	**Pilestone_B**	**Pilestone_D**	**Pilestone_E**	**Enchroma_Cx3**
O.D. [380-730nm]	0.3952	0.4203	0.3423	0.4658	0.5521
O.D. [380-580nm]	0.6311	0.8342	0.8405	0.9468	1.1874
O.D. [590-730nm]	0.1947	0.1508	0.0510	0.1786	0.2349

Table 1 – Average optical densities in different portions of the visible spectrum, computed from the glasses' spectral transmittances shown in Fig. 2.

Simulation of glasses effect on digital displays

After measuring the glasses' transmittances, we proceeded to simulate the effect of the lenses on the gamut of digital devices. This operation aims to understand whether the optical filters would be sharp enough to increase the difference between the signals generated by the M and L cones struck with the light emitted by the primaries of different devices, as well as to see whether the gamut of the filtered device would change shape.

Given the wide variety of displays on the market adopting different technologies, primaries, and gamuts, we decided to measure only two displays, one being an Acer XR341CK and the other being one of a Google Pixel 6A smartphone. Average-priced IPS displays have a gamut covering the whole sRGB color space; hence, the first chosen display is representative of most computer displays used daily at home and office. The latter has been chosen since it has a wide gamut AMOLED display, to include a different technology in our investigation. Thus, the results of this study can apply to most displays.

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The devices were measured using the same X-Rite Eye-One spectrophotometer, set in emission mode together with the i1Toolz software. The displays have been set to the maximum available brightness intensity. An HTML file showing Red, Green, and Blue *(#FF0000, #00FF00, #0000FF*) squares have been loaded, and each of the squares measured for emission using the spectrophotometer, for which the spectral readings are shown in Fig. 3.

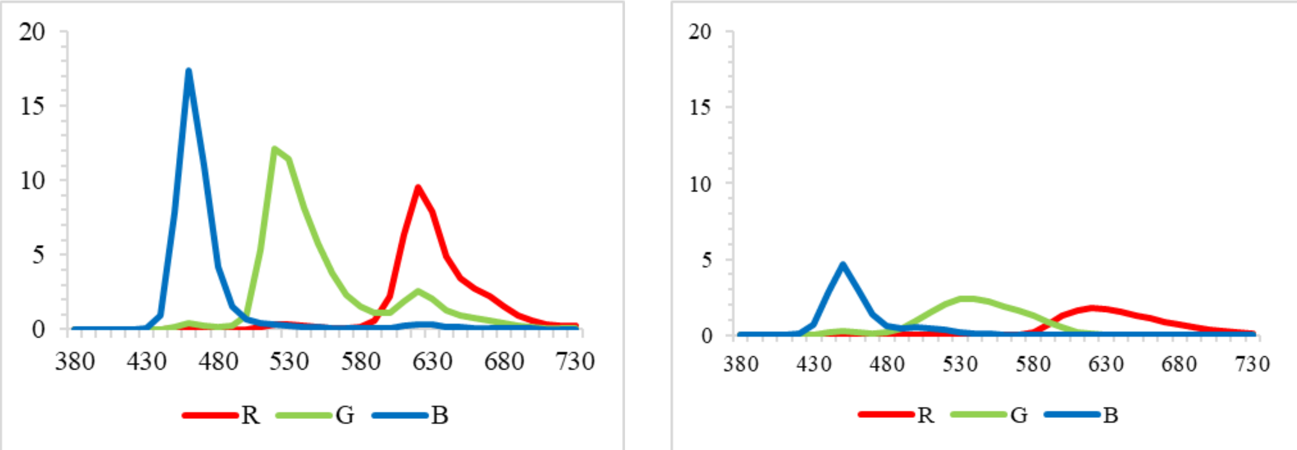

Fig. 3 – Spectral emissions of the primaries of the two displays. Google Pixel 6A on the left, Acer XR341CK on the right.Fig. 1 – Shown in these plots are: the average L, M an S cones sensitivities of a normal color observer (left), the Fig. 1 – Ones of a protanomalous observer (center) and those of a deuteranomalous observer (right). In black is shown

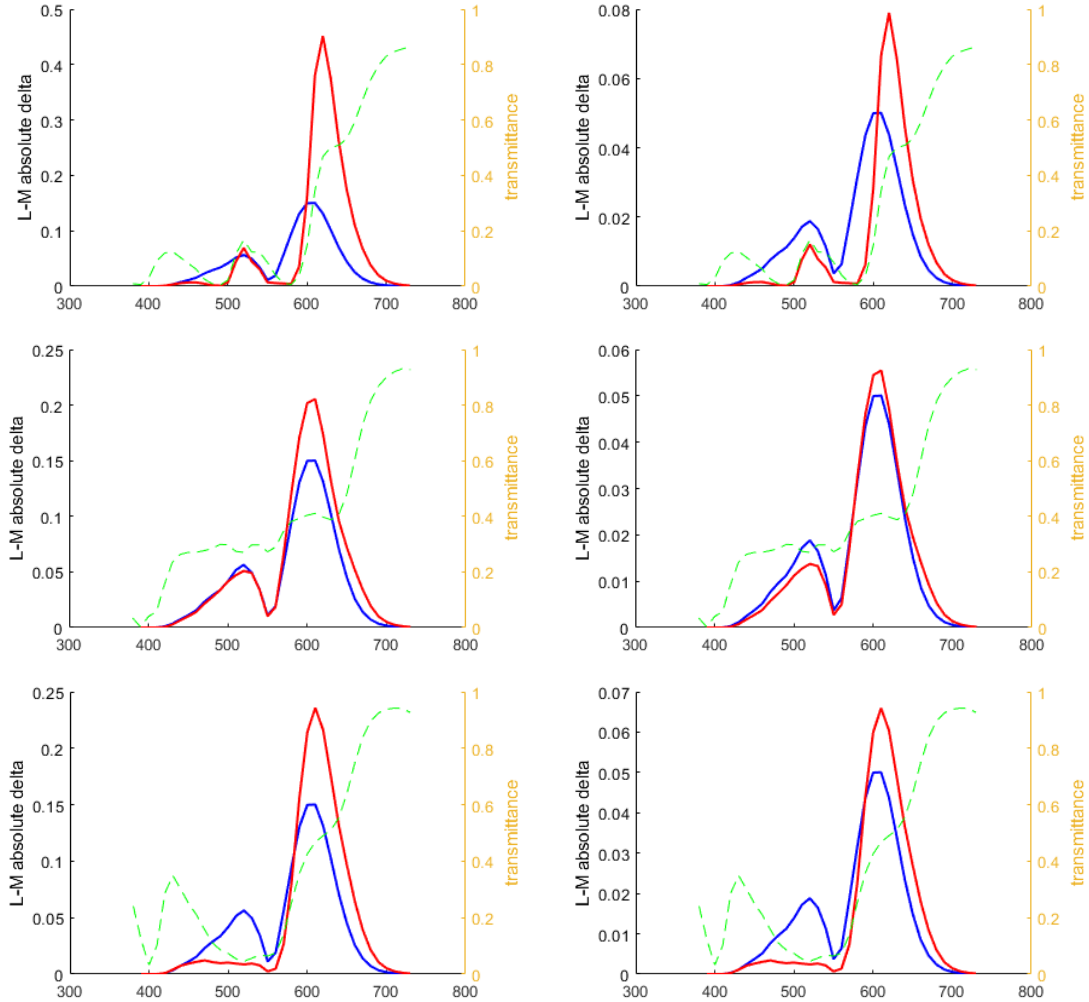

Fig. 4 – In blue is the absolute difference between the L and M cones' sensitivities (as can be seen also in Fig. 1). In red, the absolute difference between the sensitivities weighted by the transmittance of the glasses, in green the transmittance of the glasses. The left column refers to the protanomalous observer, the right to the deuteranomalous one. Top row refers to the Enchroma glasses, center row to the Pilestone type A, bottom row to the Pilestone type B.

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Results

L and M cones sensitivity differences generated by the glasses

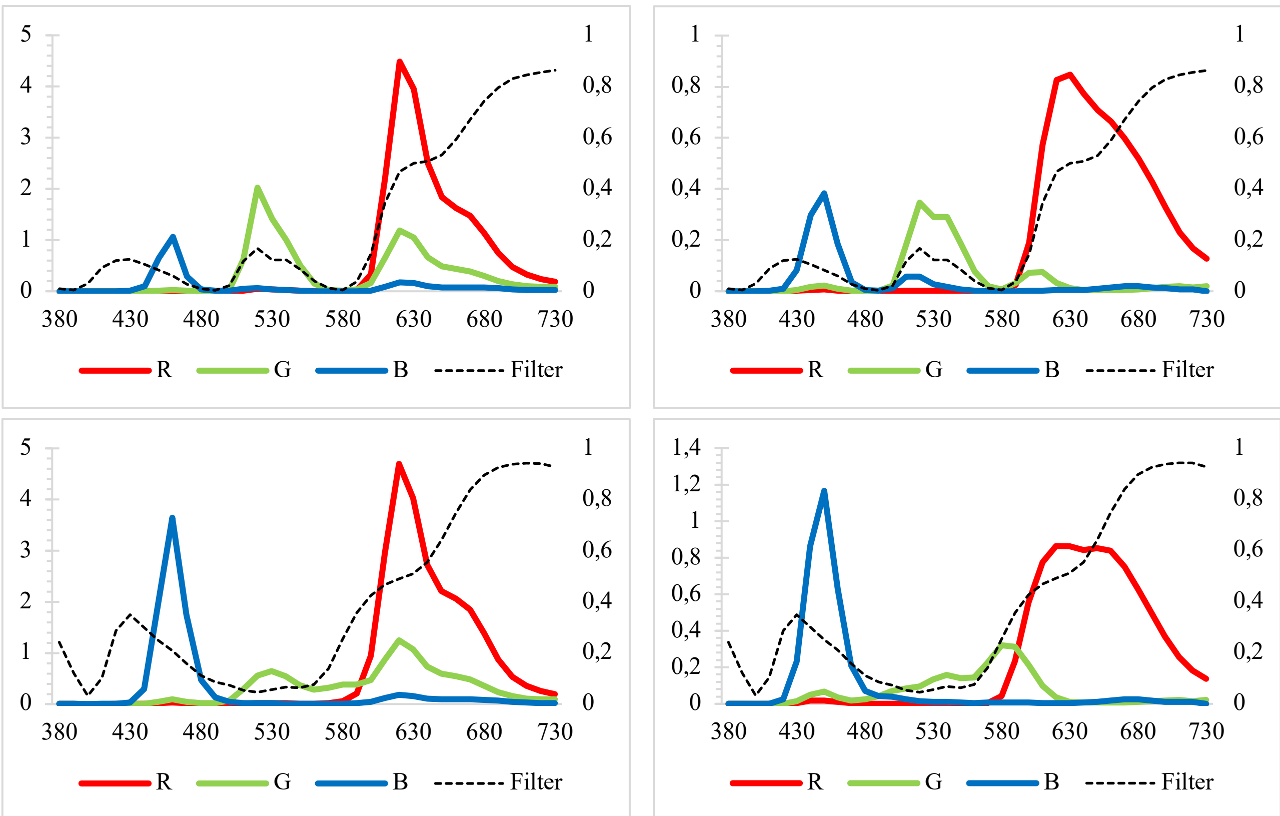
After estimating the spectral sensitivities of the cones for an ideal protanomalous and an ideal deuteranomalous observer, computing the difference between the two sets of cones using both the actual spectral sensitivities, we obtained the spectral sensitivities weighted by the transmittance of the glasses lenses. The delta between the filtered versions of the cones' response indicates the glasses' effectiveness in improving the separation between the signals generated by two cones for a given monochromatic stimuli.

Looking at the plots in Fig. 4, the most significant increase in delta between the two curves is obtained when filtering using the Enchroma glasses, at least for the wavelengths above 600nm. At the same time, the Pilestones do not seem to have such a relevant impact. It can also be noted that the filters leading to a greater separation between the L and M signals tend to reduce, if not filter out completely, the energy in certain portions of the spectrum, as can be seen comparing the type A Pilestone glasses with the Enchroma. Given the results in Fig. 4, only the Enchroma and Pilestone type B glasses will be taken into consideration in the following sections, being the effect introduced by type A the least significant.

Glasses effect on digital displays

On a purely colorimetric and pointwise approach, wearing glasses for color vision deficiency while looking at a digital display can be modeled as filtering the digital displays' primaries through the glasses' lenses. Thus, weighting the spectral emissions of the primaries by the spectral transmittance of the glasses gives a clue on the changes the visual signal coming from the device towards the retina undergoes when viewed through them (Fig. 5).

Fig. 5 – Resulting spectral emission from the primaries as filtered by the lenses. Enchroma on the top row, Pilestone



type B on the bottom row. Google Pixel 6A on the left, Acer XR341CK on the right.

It is to be noted that the peaks and valleys in the spectral transmittance of the lenses alter the shape of the emission spectra, effectively changing the chromaticity of the stimuli reaching the retina;

thus, the Introduction of a digital filter (whether it is obtained via an RGB overlay or using calibrating the device to a different white point then the native one) cannot be considered equivalent to the observation of the same display through the actual physical filters embedded in the lenses. Looking at the chromaticity plots in Fig. 6, it is clear that the gamut of the device viewed through the filters is altered, more pronouncedly in the case of the Enchroma glasses. Another observation regards the volume of the gamut, which is reduced for some pairs of display and lenses, resulting in the same pair of RGB triplets producing two chromatic stimuli closer one to the other.

Regarding the effect that glasses have on the color signal emitted from a display and reaching the retina, a modification is introduced in the chromaticity of the primaries and not only on their intensity. Clearly, the effect produced by using glasses cannot be achieved by overlaying a digital filter or performing an ad-hoc calibration of the device. Anyway, the system comprising both a real display and a pair of glasses can be simplified by a system composed of just an ideal display with custom primaries and a non-standard white point. Given some constraints (e.g., having the observer

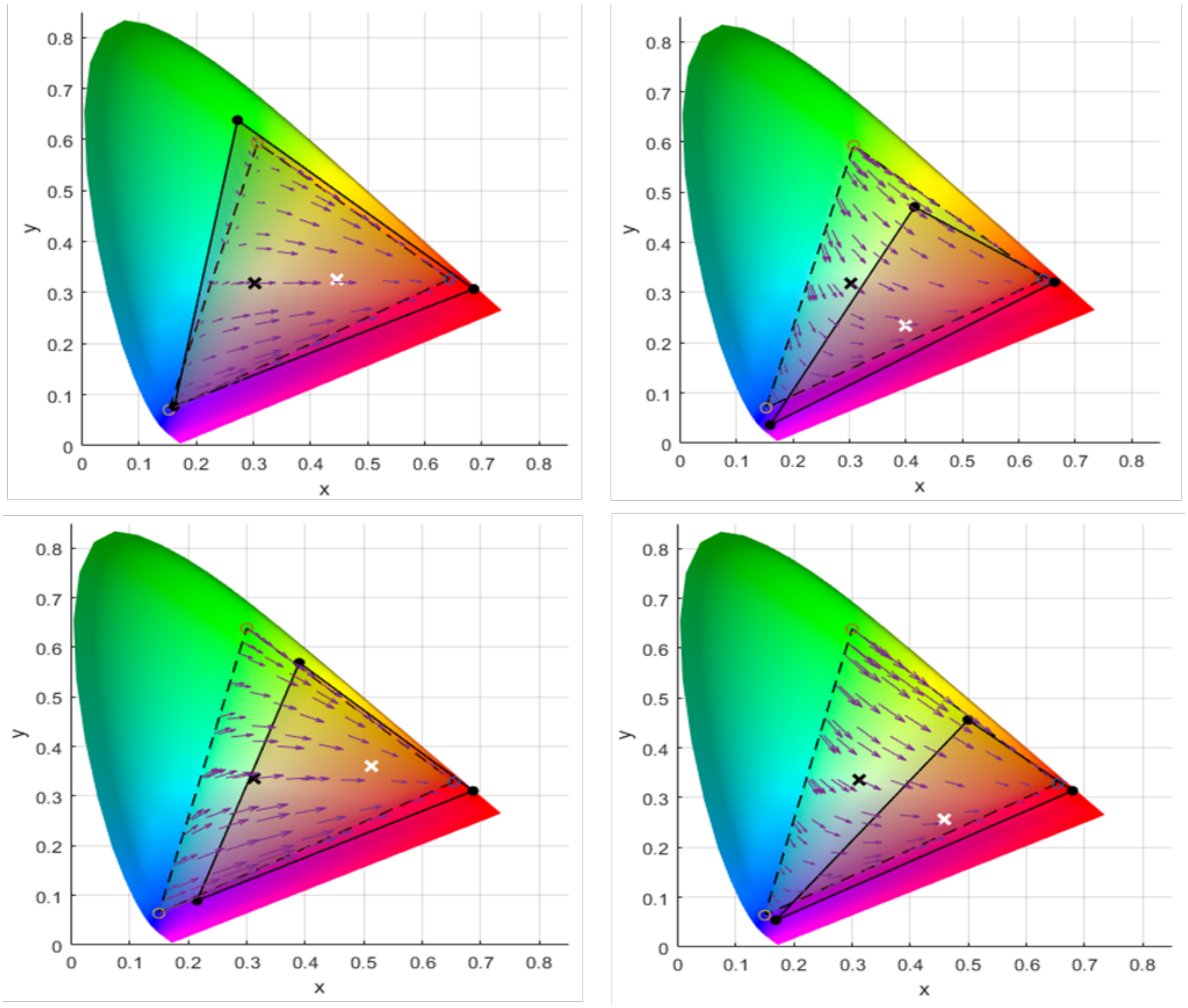


Fig. 6 – Changes in gamut of devices viewed through the glasses. At the top row is the Acer XR341CK, and at the bottom is the Pixel 6A. At the left is the Enchroma, and at the right is the Pilestone Type-B. The dashed triangle represents the actual gamut, the solid one the resulting gamut viewed through the lenses. The black cross shows the native white point (R,G,B set to the max), and the white cross is the resulting white point seen through the lenses. The arrows (on a scale of 1:5) show the direction towards which the chromaticity shifts for the same RGB triplet.

look at the display in a dark environment free from other stimuli) this simplified system is virtually equivalent to the one comprising both the display and the glasses; thus, looking at it adopting a purely colorimetric and global approach, the observation of a display A through these aids is no different from the observation of any other physical display B (with different characteristics than A) without the glasses.

It is also worth noting that the same RGB triplet effectively produces a different perceived chromaticity if the display is viewed with or without the glasses. Looking at the gamut plots in Fig. 6, it is possible to choose two RGB triplets to lead to two colors falling on the same confusion line for a given deficiency when viewed without the glasses but not through the lenses. This can certainly improve the discrimination of confused colors, but the same principle holds true in reverse, with the result of having new RGB triplets falling on the same confusion lines that would not fall without the glasses on otherwise. In this regard, another aspect worth noting is that the average direction in which the colors are shifted (Fig. 6) is much closer to the direction of the confusion lines for dichromatic protan observers than the deutan and tritan ones, possibly leading to a less pronounced effect for certain types of color vision deficiency.

Preliminary perceptive experiment

Considering the obtained results, a preliminary perceptual test has been conducted on three deuteranomalous subjects using a modified version of the online serious game *Qolour.it*. Each participant was shown the same stimuli and configuration in random order. 100 plays were made with the glasses on and 100 without the glasses. The plots in Fig. 8 show the distribution of the errors in both cases. Here, the circle width is proportional to the relative amount and severity of the errors committed (as a sum of the estimated Delta-E based on the profile of the device), the arrows show the average direction along which the errors have been committed, the two plots share the same scale. Even though this is just a preliminary test, it seems to suggest that glasses might be effective in improving the discrimination ability for some colors while worsening it for others.

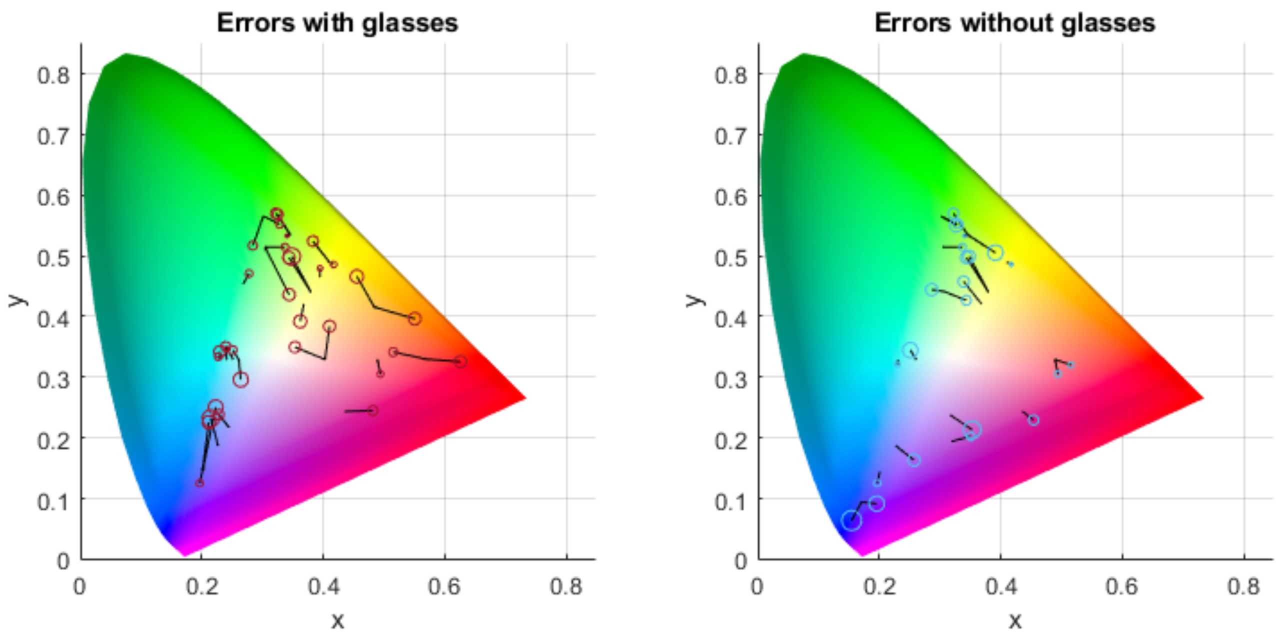


Fig. 8 – Distribution of the averaged errors committed by three deuteranomalous observers over 200 plays each of the online game Qolour.it, both with and without the Enchroma glasses on. The same Google Pixel 6A has been used to administer the test.

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Conclusion

Physical aids aimed at color-deficient people are diverse and try to reach the goal of adopting different filters with peculiar spectral responses. Some of the solutions on the market resemble colored filters, which emphasize the longer wavelengths. In contrast, others are designed to trade the color information at certain wavelengths for better channel separation. Several studies in neuroscience and ophthalmology confirm that color vision is extraordinarily complex and can not be reduced to pointwise channel transduction. Color perception also depends on brain signal processing, which is mainly spatial (McCann, 2017), and different experiments have demonstrated this effect (Rizzi, et al., 2014; Eschbach & Nussbaum, 202; Eschbach & Nussbaum, 2022). From this consideration, it is mandatory to underline the importance of defining new approaches in describing color deficiencies in developing aids and color vision tests.

In this study, we do not investigate the CVD glasses improvement in color perception. Still, we provide a colorimetric analysis of two types of glasses used for color vision deficiency aids to better understand the mechanisms behind those accessories. Thus, to make a preliminary assessment of the differences between glasses, we assessed the differential value generated by cones L and M for a monochromatic stimulus, the delta between the filtered versions of the cones' response, and the filtering of the RGB primaries of some representative displays through the glasses lenses. These analyses, together with a preliminary perceptive experiment, allow us to assess that, in some cases, CVD glasses can improve the color discrimination of color-deficient people, but just in specific conditions and for a particular set of colors.

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5. Color and Restoration

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Coloured cities: iconography and scientific evidence for colours reconstruction of built heritage in central Italy

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Abstract
The present paper analyses the possibilities in clearly characterising and reconstructing the colour of cities during the Middle Ages and through the examination of painting iconography and materials evidence of some of the most important and well-represented cities of central Italy, such as Siena, Assisi and Arezzo. A study of buildings external appearance is obtained by comparing the construction materials and related conservation issues and the architectural references in painting iconography. The study of the historic urban context compared to large-scale religious and/or civil buildings is often more complex due to the scarcity of archival-library sources and sometimes to the loss of part of the construction material, especially in correspondence of the surface layers. The analysis of materials presented in this paper is carried out from a structural and architectural point of view as well as in terms of colour, on the basis of the properties of the type of stone and/or marble, plaster and superficial finishes. This study will demonstrate that thanks to the study of the building materials, the state of conservation of surfaces and the retrospective evaluation of the processes of alteration and degradation of materials, it is possible to read the ancient iconographic painted sources in a more scientific and in-depth way.

Keywords: built heritage, colour appearance, painting iconography, surface finishes, mediaeval architecture.

Introduction

Common dwellings undergo multiple modifications over time and their contribution to the history of architecture in important cities, although extremely significant, has always been considered subordinate to those once viewed as major buildings. Furthermore, structure and shape are the first features considered in the reconstructive and restoration processes of any architectural element, and, only later, if necessary, the colour is applied to the surfaces, attributed by analogy with less awareness of other characteristics due to the lack of reliable data. The described processes lead to considerable uncertainty in terms of reconstructing the colour of public spaces, especially for built heritage in different historical periods. Loss of colour traces in artworks is an important and delicate issue in Cultural Heritage (CH) field, both for artistic reasons and for the testimonies of technical knowledge of various historical periods (Ceccarelli *et al.*, 2021). Recent research on architectural historical finishes and on stone alteration underlined the importance of deepening the study of material building techniques, especially in Central Italy (Grossi *et al.*, 2003; Hajpál and Török, 2004; Grossi and Brimblecombe, 2007; Vazquez-Calvo *et al.* 2007; Cutler *et al.*, 2013; Sousa and Gonçalves, 2013; Scopinaro *et al.*, 2017). Furthermore, the numerous seismic events that characterised central Italy during the centuries have led to important loss of materials in such historical buildings, also losing evidence of colours. Indeed, with the exception of a few rare examples, it is very difficult to find nowadays traces of surface decoration on historical buildings, especially when it comes to late ancient and mediaeval ages. Nevertheless, by examining the walls with bi-chromatic and poly-chromatic decorations, obtained by the juxtaposition of materials with different colours, it is possible to outline some aspects of the original appearance of mediaeval cities.

The most frequently used techniques also for external decoration in built heritage were frescoes, lime, and lime casein paintings, and - rarely - oil paintings. Moreover, in the late mediaeval ages a common practice was to add painting decorations with pre-formed moulds, etched plasters and glazed terracotta (Borgherini, 2001; Fiorani, 2008). These decorations were made to emphasise the architectural design and to highlight the most important structural elements, making exterior facades more decorated and colourful (Fachechi, 2016). Even in cases where the wall facings were realised with excellent construction materials and designed as unplastered, it cannot be excluded that the surfaces may have been treated with further finishes in order to make uniform the obtained patterns, emphasise the colour tones and/or preserve the surfaces. For example, this could be the case of the colouring treatments on Siena cathedral surfaces (Droghini *et al.*, 2007, 2009) and the decorative paintings on Amiens cathedral main façade (Ribeyrol, 2020). Nevertheless, over the years the appearance of surfaces could have been changed. Sometimes it is easier to trace major changes, such as those caused by natural disasters (e.g., earthquakes, landslides, floods, etc.) or destruction due to conflicts, but most of the times it is difficult to discern the original appearance of the material from the deteriorated one due to natural degradation phenomena. Thus, originally, the historical buildings could have had a much more colourful aspect which changes during the centuries because of several factors such as loss of architectural finishes and discolouring of the construction materials, mainly due to external exposition. The aim of this contribution is to provide a comparative study of the iconographic sources, which have become increasingly interesting starting from the end of the Middle Ages, highlighting the link between the sources, the raw materials for the building's construction and the original appearance of the stones.

Iconography of colour in building surfaces

In Italy, painted architecture almost disappeared from the fall of the Roman Empire to the late Communal Era (White, 1973). As the painting techniques transformed and evolved, also the way of depicting architecture changed during the first half of the 14th century in central Italy. City views became more accurate and realistic in terms of building materials characterization, volumetric definition, location and also colour. The greater relationship between painted and built architecture offers a new perceptual relationship through comparative examination of iconographic sources and, in some cases, real architecture. In this paragraph, the analysis of the colours in building depictions are carried out on masterpieces of three cities of central Italy, namely Assisi, Siena and Arezzo.

Assisi

The most famous examples of the development and the change in architecture depiction can be found in Giotto's paintings, where the structures are no longer an iconic background to the scenes but take on a prominent and diversified role becoming 'real'. As can be seen from Fig.1a reporting a detail of the fresco of Saint Francesco in the Assisi Basilica, the function of the architecture in the representation is mainly topographical: it helps the observer to contextualise the scene, placing it in the city of Assisi, through its most characteristic and central building, the ancient temple, which is the only and the most important local memory of Roman architecture (Greenhalg, 1984; Settis, 1986). The temple of Minerva in Assisi is the first example of a recognizable mediaeval architectural depiction and this role gives it a visual and symbolic meaning (Benelli, 2016). Although the temple is perfectly recognizable, it has some differences with the real building (Fig 1b): only five columns are represented on the facade instead of six; the entablature has a Cosmatesque motif instead of the classical one and the absence of the central door under the portico. All these elements served the artist to modernise the monument and make it more Catholic (Jauss, 1982). Despite the differences, however, the characterisation of the construction materials and their colours seems to be reliable. In fact, the representation underlines the alternation in the use of marble and limestone in the pronaos of the temple and emphasises the colour of the *Palazzo del Capitano del Popolo*, which is the pink-stone building located to the left of the temple. Regarding the latter architectural element, even if the today whitish appearance of the building could lead to think about an error in the colour representation made by Giotto, the use of the pinkish Assisi stone as construction material of the building could confirm the artist depiction reliability, indicating a degradation in colour of the stone (Vannucci *et al.*, 1982; Scopinaro, 2020). As the city is an important centre of the catholic tradition, the use of local pink stone provides an added value in the urban architecture that is therefore strongly linked to the local geological landscape. For what concerns the greenish structures on the right of the temple, no evidence is available on the kind of buildings they were nor on the construction materials, being today replaced with modern ones. It can be assumed that in this case the colour of the building was also chosen to contrast and balance with the rest of the representation, without deviating too far from the colour of the local limestone, an almost exclusive construction element in Assisi.

(a) (b)

Fig.1 - Assisi coloured urban context: a) Giotto di Bondone, L'omaggio dell'uomo semplice, 1290-1292, fresco, Assisi, Basilica superiore di San Francesco (in Benelli, 2016, p.27, f. 3); b) photograph of the today asset of the Assisi city hall square (credits:GoogleMap).

Siena

Ambrogio Lorenzetti's fresco cycle *Allegoria ed effetti del Buono e del Cattivo Governo* (1338-'39) summarises a period of pictorial innovations introduced mainly by Giotto (Donato, 2002). The painting *Effetti del Buon Governo in città* (Fig.2a) in the *Palazzo Pubblico* in Siena shows for the first time a scene of urban life. The city is represented with a good view of the buildings, but there is a lack of recognisable 'portraits' of local monuments, with the exception of two elements that still allow the identification of the depicted city as Siena: the dome of the Cathedral and its bell tower (Fig.2b), and the she-wolf suckling the twins on the exterior façade of the city gate (Fig.2c), symbol of the city. It is possible to assume that the subject is the contemporary city of Siena represented as close as possible to reality (Belting, 1985). Moreover, according to Francesco Benelli's interpretation (Benelli, 2016), the absence of the Palazzo Pubblico and any buildings associated with it could be explained by assuming that the observer either has his back to the palazzo or is inside it and turns his gaze north-westwards beyond the piazza. Such a view would also justify the inclusion of the bell tower and dome of the cathedral in the upper left-hand corner of the painting. Following this hypothesis, it is possible to trace the specific characteristics of several known structures including private palaces and public buildings, probably because the author's intention may have been to represent the specifically Sienese typology of buildings and the city. The painting's colours are mainly by reds and greys, recalling the main building materials of mediaeval Siena such as the red of brick and the grey of tower stone (Gabbrielli and Giamello, 2022).

(a) (b) (c)

Fig. 2 - Siena coloured urban context: (a) Ambrogio Lorenzetti, *Effetti del Buon Governo in città*, 1338-1339, fresco, Siena, Palazzo Pubblico, Sala dei Nove; details of the depiction of (b) the dome and of the bell tower of the Cathedral and (c) she wolf, symbol of the city. (in Frommel and Wolf, 2016, pp. 174-175, f. 18).

Arezzo

The painting in Fig.3a represents the scene of *La Cacciata dei diavoli da Arezzo*, one of the best-known episodes in the life of San Francesco of Assisi ("the "Expulsion of the Devils from Arezzo"). The scene shows Friar Silvestro in front of the city, raising his hand to order the devils that fluttered over Arezzo to leave, and behind him San Francesco in prayer. On the left of St. Francis and Friar Sylvester, the Gothic-style cathedral is depicted with the whitish structure and the red roofs, while on the right is depicted the city with very coloured buildings protected by massive walls. Such vibrant colours could come from the artistic licence of the painter, maybe starting from a coloured (yellowish) appearance of the buildings due to superficial treatments. Indeed, as mentioned before, this kind of treatment was intended to uniform the colouring of wall-facings, for example in the case of the yellowish buildings, making them resemble ivory by the use of pigments such as yellow ochre.

Fig. 3 - Arezzo coloured representation from Giotto fresco "the Expulsion of the Devils" inside the Assisi *Basilica* (in Benelli, 2016, p.33, f. 9).

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Stone appearance analysis

Central Italy is characterised by different geological environments with many geomorphological peculiarities, leading to a great variation of materials available for the construction of buildings used over the centuries, as described in the above-mentioned paintings. Such variation, and the subsequent surface aspect of the materials, has strongly influenced the location of urban sites and the building typology, usually made of the local raw materials, connecting the urban context and built heritage with the geological and geomorphological history of the area (Gregori, 2006), element strongly depicted by the great masters as Giotto and Lorenzetti. In particular, the areas of the considered cities in this work are predominantly characterised by the lithotypes of the *Umbro-Marchigiana* series of the Mount Subasio for what concerns Assisi (Vannucci *et al.*, 1982), *Montagnola Senese* relief for Siena (Giannini and Lazzarotto, 1970) and *Macigno* Formation for Arezzo (Cipriani and Malesani, 1964; Aruta, 1994). In the specific case of Assisi, the limestone typical of this area, coming from the *Scaglia Rossa* formation, is known as 'Assisi stone' (Fig.4a) and it is characterised by a peculiar 'pinkish' hue, where red flint nodules are frequent. Furthermore, the white variation of the same lithotype, called *Scaglia Bianca*, is often found in association with the pink stone, as can be seen in the church in Fig.4b.

(a) (b)

Fig. 4 - Assisi stone: a) aspect of the *Scaglia Rossa* formation and its use in religious buildings such as Saint Peter church in Assisi (b). (credits: E. Scopinaro).

The same lithological bi-chromatism (white-red) is also found in the material used in the construction of the palaces and symbolic monuments of the most leading cities of Umbria, especially along via Flaminia, e.g., Perugia, Assisi, Foligno, Spoleto, Todi, Spello (Scopinaro, 2017). In the same geomorphological area, there is also the *Scaglia Cinerea*, consisting of grey marly limestones often used for cities buildings in the umbrian territory. The overall colour is rather uniform, although there may be present pinkish impurities that make it sometimes difficult to distinguish between the *Scaglia Variegata* and the *Scaglia Cinerea* (Petti and Falorni, 2017).

The area of Siena is characterised by several lithological variations, mainly found in the Montagnola Senese formation, from which were quarried several materials such as the yellow marble (*Giallo di Siena*), the whitish-grey marble (*Grigio Perla*), as can be seen in the Lorenzetti painting in Fig.2a, and the *Calcare Cavernoso*, also known as 'tower stone' for its extensive and distinctive use in this type of construction (Gandin *et al.*, 2000). Finally, the famous white-green and/or black-white bi-chromatism that characterises many religious buildings of the mediaeval age in the central Italy architecture is mainly obtained with the use of the serpentinite. This is a metamorphic rock with predominantly black coloration with dark green flecks, quite strong thus suitable for construction purposes, mainly coming from the territories of Murlo or Vallerano (Fratini and Rescic, 2014). This is, for example, the main material used for the construction of the Siena Cathedral, clearly discernible from the Lorenzetti painting (see Fig.2b).

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The main stone used in the area of Arezzo is the variation macigno known as *Pietra Serena*, consisting in a medium-grained sandstone with a grey-blue colour to yellow-ochre (Aruta, 1994). This stone is widely used in all the Arezzo areas from ancient times as solid construction materials, for pavements, columns, towers and walls, as can be seen in the depiction of Arezzo Cathedral and walls by Giotto.

Conclusions

In this work, the theme of colour in the ancient representations of mediaeval cities is addressed by analysing and comparing the iconographic sources provided by famous painters with the natural appearance of the actual used stones. From such study it can be stated that the image of central Italian cities has changed over the centuries, but not all the modifications are clearly visible. Where structures still exist and have at least partially preserved their original form and function, it is easy to assume that other features could not have been altered. Conversely, the passing of centuries, the alternation of seasons and the weathering cause important and irreversible changes in the appearance of buildings and, consequently, of cities. In addition, the continuous socio-cultural and economic transformations led to modifications also in the concept of the city and the urban context, starting from the ancient practices of removal and reuse of construction materials over the years. The modifications of architectural structures based on changing needs over the years (e.g., changes in function, style, size and proportions) provide modifications on the structure of the building itself. The analysis of surface changes could not only provide technical and scientific indications for conservation but could also guide scientific investigations to reconstruct and link different moments of construction, abandonment, restoration and reuse within a building and cultural context, or to confirm/refute theories based on indirect sources (Boato, 2008). Degenerative pathologies are all connected to the history of the construction, the physic-chemical nature of its materials, the atmospheric agents of degradation, the personal experiences of builders and artisans, as well as those who contributed to its preservation or made any use of it (Mannoni, 1996). Concerning the external finishes, if for marble surfaces and other decorative materials, such as Serpentinite and fine marbles, the use of plaster, even pigmented plaster, is something to be ruled out, in the case of masonry with ordinary materials, such as brick, it becomes a matter of course. However, the painted works chosen in this study are unable to tell us how the colorations were achieved, whether with the stones and bricks left in their natural state or with a pigmented plaster. Thus, as a future perspective, a careful analysis of the ongoing degenerative processes on the studied materials is essential not only to evaluate the best solutions for protection and restoration but also to scientifically support investigative actions aimed at identifying different construction and execution techniques and reconstructing possible finishes in terms of colour and texture.

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Spectroscopic investigation of synthetic dyes on 1980-90s Sicilian '*Prisenti*'

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Abstract

In this work, preliminary spectroscopic analysis of three '*Prisenti*' processional clothes from the 1980-90s, are presented. Six areas (three belonging to the first cloth, two from the second and one area for the third cloth) were investigated through Fiber Optic Reflectance Spectroscopy (FORS) and micro-Raman spectroscopy. FORS data helped in identifying the dyes used, while μ-Raman spectroscopy enabled a more precise identification of the synthetic dyes. Overall, positive results were obtained in terms of distinguishing the molecular class of the dyes, and in some cases, the specific dye structure was hypothesized by comparing the spectrum with online databases.

Keywords: synthetic dyes, textiles, non-invasive, spectroscopy.

Introduction

Cultural heritage studies focusing on objects dyed with synthetic colorants represent a relatively new area of study due to their modernity. However – despite only a few centuries passed since their discovery – there is an increasing interest in the research of modern synthetic material. This subject bears significance not solely in the context of unrevealing early industrial production methods, thereby shedding light on the historical panorama of fashion and manufacturing, but also in the formulation of novel strategies for heritage conservation. The lack of long-term testing for synthetic substances, in contrast to their traditional counterparts, has contributed to a limited comprehension of their behavior over time. Among synthetic materials, synthetic organic dyes and pigments pose a particular challenge for conservators and researchers (Cwiertnia and Bosi, 2022) Some of these substances, especially the earliest ones, have demonstrated vulnerability to light and solvents. Consequently, the characterization of synthetic colorants becomes imperative in adapting prevailing preventive conservation methodologies to the realm of artworks. Furthermore, the identification of synthetic colorants assumes a role as a dating criterion for art pieces, given their production in recent epochs and their well-documented commercialization timelines. However, the unequivocal identification of these colorants often proves difficult due to complex analytical challenges related to their chemistry. Like natural colorants, non-invasive identification of synthetic colorants is complicated due to the matrix effect. Moreover, their chemical structures can be very similar (Lomax and Learner, 2006), and the diversity of molecular classes is further complicated by different companies using non-standardized names for chemically identical compounds (or the same names for chemically different dyes)(Barnett, 2007). Conventional methodologies utilized for the detection of organic dyes encompass chromatographic techniques, notably high-performance liquid chromatography coupled with diode array detection (HPLC-DAD) or mass spectrometry (HPLC-MS) (Terán *et al.*, 2021). Additionally, pyrolysis gas chromatography coupled with mass spectrometry (Py-GC/MS) has also been used for synthetic organic pigments, although it has restrictions concerning the discrimination of individual compounds and sensitivity(Ghelardi *et al.*, 2015). Furthermore, X-ray diffraction has been demonstrated to be an effective tool for the specific identification of synthetic organic pigment mixtures and fillers in acrylic and alkyd binders(Brostoff *et al.*, 2009). Regardless, when dealing with objects of art, the application of techniques requiring sampling is discouraged and a multi-technical approach including non-invasive and eventually micro-invasive techniques is always preferred. A spectroscopic approach represents an appropriate solution for this purpose. In this sense Fiber Optic Reflectance Spectroscopy (FORS), especially in its portable configuration, is a validated tool for the preliminary identification of dyes and artistic materials in general, due to its portability and ability to perform non-invasive in situ analysis(Bacci, 2000; Cazenobe *et al.*, 2002). Also, vibrational spectroscopy, and in particular Raman and Surface Enhanced Raman Scattering spectroscopies (SERS) have attracted the interest of many, as these techniques can offer a deeper knowledge of the molecular class to which the dyes belong(Pozzi and Leona, 2016).

Within this study, we present an initial spectroscopic examination of three processional garments, colloquially referred to as '*Prisenti*,' originating from the 1980s-90s. Employing both FORS and micro-Raman spectroscopy, six distinct areas (three from the first garment, two from the second, and one from the third) were analyzed. The acquired data were subsequently processed, and the outcomes were juxtaposed with online databases to facilitate molecular characterization of the synthetic dyes.

Materials and Methods

Sicilian 'Prisenti'

Prisenti are processional clothes used for the celebrations of San Rocco in Gibellina (Sicily), which were traditionally handcrafted by the women of the town for the celebration of the Holy Cross Feast Ranni. The tradition was revived in the post-earthquake period in the 1980s by the mayor at the time, Ludovico Corrao, and linked to the festivities in honor of San Rocco, becoming an occasion to celebrate the culture, art, and traditions of Gibellina. Each year, a contemporary artist was invited by the mayor to design and create a processional cloth. The three *Prisenti* studied in this work belong to the parades of years 1988, '89 and '90 and were designed respectively by Giuseppe Santomaso (Fig.1), Giulio Turcato (Fig. 2) and Carlo Ciussi (Fig.3). All of them belong to a different current of the abstractionism movement.

Fig. 1 - *Prisente* by Giuseppe Santomaso (1988), 8.40m x 2.25m: collage of synthetic fabrics depicting abstract forms. Giuseppe Santomaso was a representative of both Lyrical and Expressionist Abstract art.

Fig. 2 - *Prisente* by Giulio Turcato (1989), 8.00m x 1.32m: collage of cotton fabrics with applications of silk faille, depicting geometric forms typical of Italian Informal Abstraction, of which the author is the main exponent.

Fig. 3 - *Prisente* by Carlo Ciussi (1990), 8.00m x 1.21m: collage of fabrics consisting of a jute base decorated with various curvilinear designs in cotton velvet, typical of graphic abstraction, to which the author adhered after an initial figurative phase.

Table 1: List of samples analyzed.

Sample	Type	Prisente	Colour
1C	thread	by Giuseppe Santomaso (1988)	red
1F	textile	by Giuseppe Santomaso (1988)	blue
1H	thread	by Giuseppe Santomaso (1988)	brown
2A	textile	by Giulio Turcato (1989)	yellow
2B	thread	by Giulio Turcato (1989)	pink
3D	thread	by Carlo Ciussi (1990)	dark

Experimental

FORS data were acquired in the UV-Vis-NIR range using the EXEMPLAR LS BW TECH spectrometer (Plainsboro Township, NJ, USA), operating in the range 180–1100 nm with a variable resolution of 0.6 to 6.0 nm. Samples were illuminated using a 5W BW TECH BPS101 halogen lamp with an emission spectrum between 350 and 2600 nm and a colour temperature of 2800 K. Radiation was sent to (and collected from) the samples using THORLABS RP22 optical fibre bundles provided with a measuring head of 45° inclination, which was suited to avoid the collection of specular reflectance radiation. For each sample, five spectra were acquired in different points of the thread, and they were then averaged and processed using OriginLab 2018.

Micro Raman measurements were conducted using a Horiba Jobin-Yvon HR-Evolution Raman spectrometer (Kyoto, Japan) coupled with a microscope equipped with a series of interchangeable objectives. In particular, a 20x magnification was used to choose the area of interest while the 50x objective allowed the laser beam to focus on the point of analysis. The samples were excited with a He-Ne laser source (λ = 632 nm) and the intensity varied between 0.3 and 1.5 mW. The acquisition times and the number of scans were chosen for each sample in order to optimize the signal/noise ratio. Again, three to five spectra were acquired for each colored thread, and data were processed using the OriginLab 2018 software. Eleventh-grade polynomial baseline was subtracted for the background and the 'adjacent-averaging' smoothing method was applied to reduce noise. If reproducible, spectra of the same sample were averaged.

Results and Discussions

In all the acquired spectra it was not possible to recognize any typical spectral features of textile fibers. According to this, it is reasonable to assume that the spectral information obtained from both FORS and Raman spectra is due entirely to the presence of organic dyes. In the following paragraphs, results for the six samples (a completed list is reported in Table 1) extracted from different areas of the three Sicilian *Prisenti* analysed are reported.

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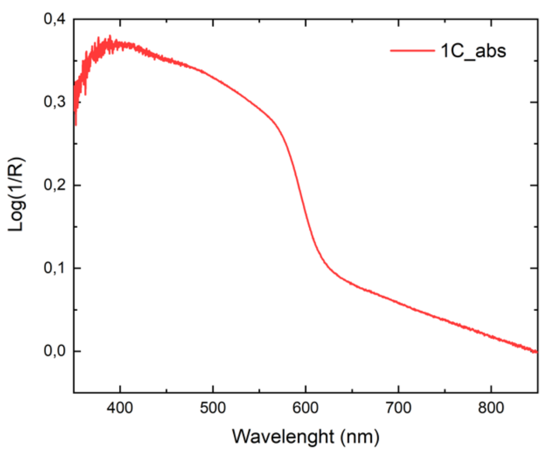
***Prisente* by Giuseppe Santomaso (1988)**
The UV-Vis spectrum of sample 1C (Fig. 4a), representing the red thread collected from Santomaso's *Pisente*, exhibits the characteristic sigma shape commonly associated with red dyes (Fonseca *et al.*, 2019). The presence of an absorption peak around 400 nm, accompanied by a shoulder ranging from 480 to 570 nm, indicates the probable classification of this compound within the dis-azo dye category (Montagner *et al.*, 2011; Caggiani *et al.*, 2022). This hypothesis is further corroborated by the corresponding Raman spectrum (Fig. 4b). The three most prominent peaks, observed at 1612, 1584, and 1559 cm^{-1}, are indicative of vibrational modes inherent to dis-azo colourants. Specifically, the peaks at 1612 and 1584 cm^{-1} correspond to the vibrations of the aromatic ring and dis-azo modes, while the peak at 1559 cm^{-1} is linked to the amide band (Lomax *et al.*, 2019). The peaks around 1400 cm^{-1} also correspond to the N=N stretching of the azo groups(Lomax *et al.*, 2019; *SOPrano Spectral database*, 2023).

The Fiber Optic Reflectance Spectroscopy (FORS) analysis of the blue sample (1F, Fig. 5a) instead reveals the presence of two absorption bands at 612 and 670 nm, along with flexes at 630 and 670 nm. This distinctive spectral profile prompts speculation, based on comparison with existing literature databases(Montagner *et al.*, 2011), that this sample also belongs to the dis-azo dye class, possibly identified as Benzo Sky Blue (Direct Blue 15). Despite no established Raman reference for this compound could be identified, an examination of peak assignments (Fig. 5b) suggests its dis-azo nature. Specifically, the vibrational mode of the azo benzene group is evident at 1538 and 1508cm^{-1}, while the vibrations of the naphthalene group are discernible at 1340 and 750 cm^{-1} (Lomax *et al.*, 2019; Castro *et al.*, 2020).

The UV-Vis spectrum of the brown thread (sample 1H), presented in Figure 6a, displays an absorption band centred around 400 nm and a shoulder at 520 nm, accompanied by a flex around 690 nm. Despite efforts to correlate the spectral features with established databases of brown dyes, no definitive chemical nature could be attributed to this dye. Conversely, the Raman spectrum (Fig. 6b) suggests the potential presence of a nitro-based synthetic dye, indicated by the prominent band at 1327 cm^{-1}, characteristic of the NO^{3-} group. Particularly noteworthy is the alignment with an online database (*SOPrano Spectral database*, 2023), supporting the supposition that this colorant could be PBr22 (C.I 10407).

a



b

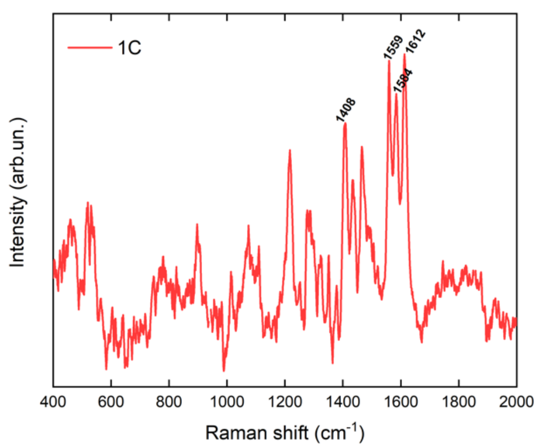


Fig. 4: FORS (a) and Raman (b) spectra of sample 1C. Here a baseline was subtracted to enhance and appreciate Raman peaks; hence artifacts around 600, 1000 and 1380 cm^{-1} could observed in the Raman spectrum.

a

b

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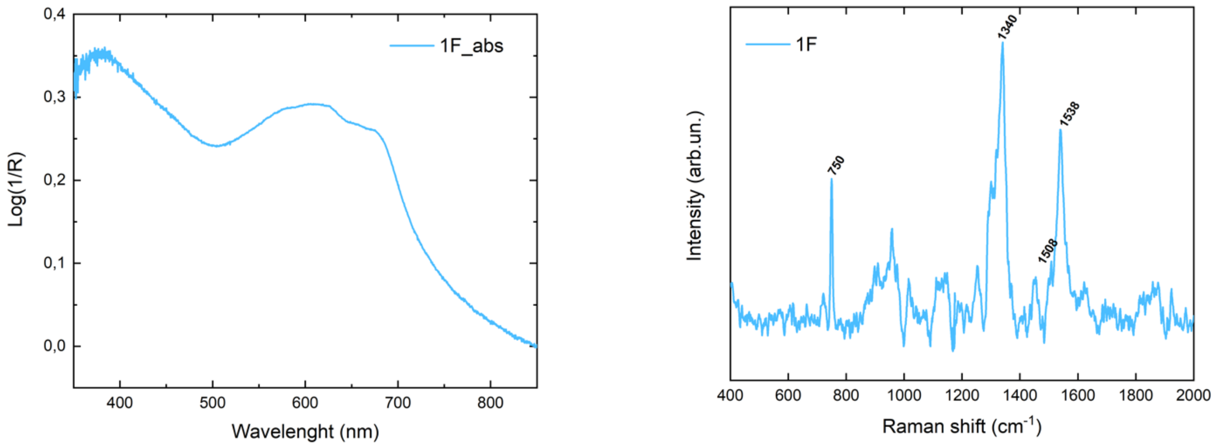

Fig. 5: FORS (a) and Raman (b) spectra of sample 1F.

a b

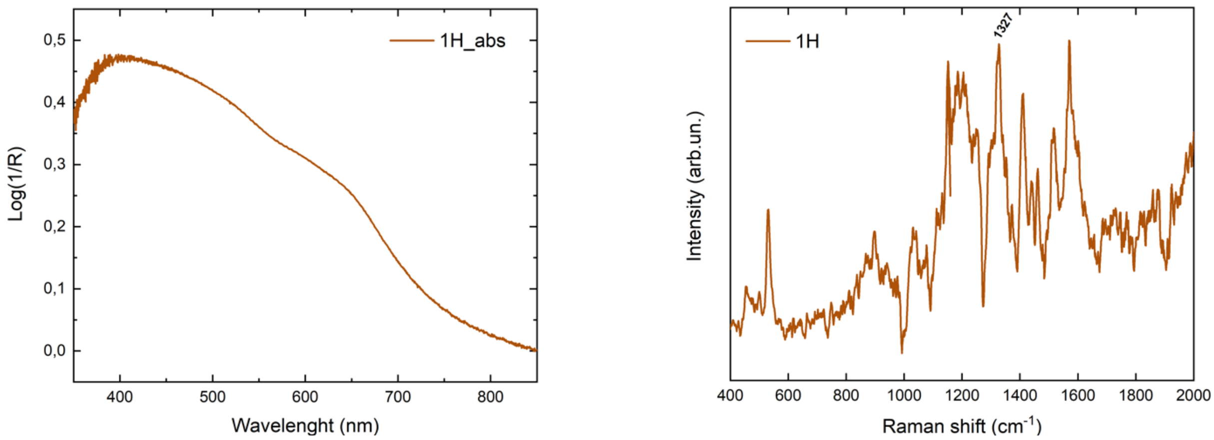

Fig. 6: FORS (a) and Raman (b) spectra of sample 1H. Here a baseline was subtracted to enhance and appreciate Raman peaks; hence artifacts around 1000 and 1227 cm^{-1} could observed in the Raman spectrum.

***Prisente* by Giulio Turcato (1989)**

The UV-Vis spectrum of sample 2A (Fig. 7a), attributed to the *Prisente* by Giulio Turcato, exhibits an absorption maximum at approximately 400 nm and a shoulder at 470 nm. Upon comparison with established spectral databases in the literature, the presence of a yellow dye from the thioflavin class becomes discernible(Voropai *et al.*, 2003; Caggiani *et al.*, 2022). Pertinent references in the literature also furnish Raman data that support the assertions derived from the FORS data. Particularly intriguing is the consideration of the Thioflavin T Raman spectrum presented by (Lopez-Tobar *et al.*, 2013) where intense peaks are present at 1544, 1400 and 1131 cm^{-1}. However, upon comparing the Raman spectrum of sample 2A (Fig. 7b) in relation to the reference spectrum, it becomes evident that the frequencies are shifted and do not exhibit precise alignment. Instead, a more pronounced spectral resemblance emerges upon comparing with Raman spectra of yellow dyes belonging to the mono-azo class. Of notable significance is the very intense peak at 1595 cm^{-1}, alongside other notable peaks such as those at 1522, 1293, 1253, 1224, and 1096 cm^{-1}. This collective evidence suggests that Solvent Yellow 16 may be present within sample 2A (Muehlethaler *et al.*, 2017).

For the characterization of the dye found in sample 2B, two plausible hypotheses paths, both supported by FORS and Raman data, can be followed. The UV-Vis absorption spectrum (Fig. 8a) reveals absorption peaks at 387 and 509 nm, accompanied by a centered shoulder around 555 nm. An inflexion around 595 nm is also discernible, alongside the peak reflectance at 437 nm. Considering comparisons with literature databases(Montagner *et al.*, 2011), it is conjectured that this dye may belong to the triarylmethane class, with possibilities including Magenta or Fucsin, or alternatively to the xanthene class, potentially as Eosin. The corresponding Raman spectrum (Fig. 8b) showcases strong peaks at 1619, 1569, 1432, and 1276 cm^{-1}. In accordance with the findings outlined in (Doherty *et al.*, 2014), these peaks occupy characteristic spectral regions for triarylmethane dyes. However, in congruence with (Narayanan, Stokes and Vo-Dinh, 1994), the peaks at 1619, 1432, and 1276 cm^{-1} are indicative of vibrational modes associated with Erythrosine B, a fuchsia dye within the xanthene family.

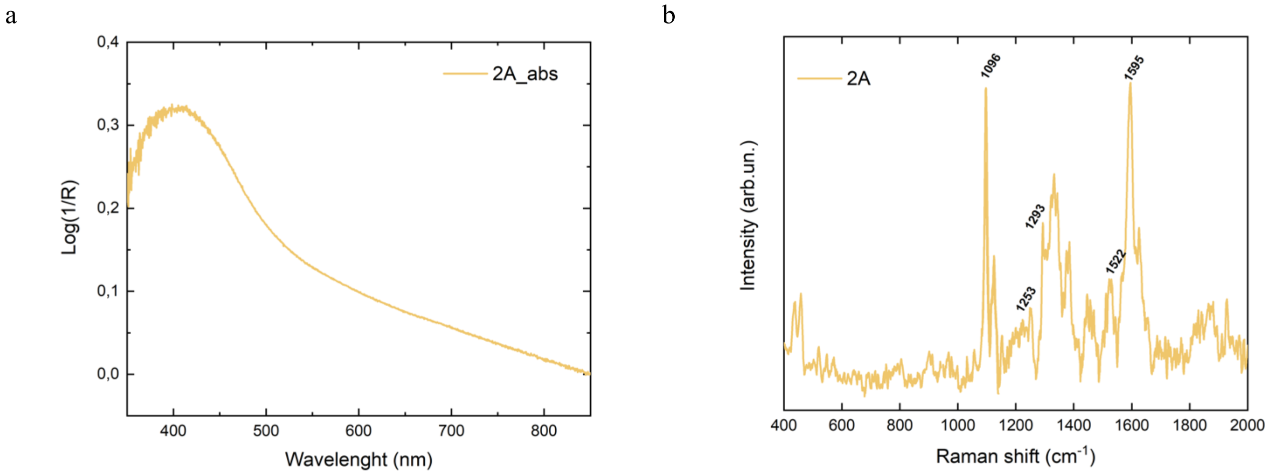

Fig. 7: FORS (a) and Raman (b) spectra of sample 2A.

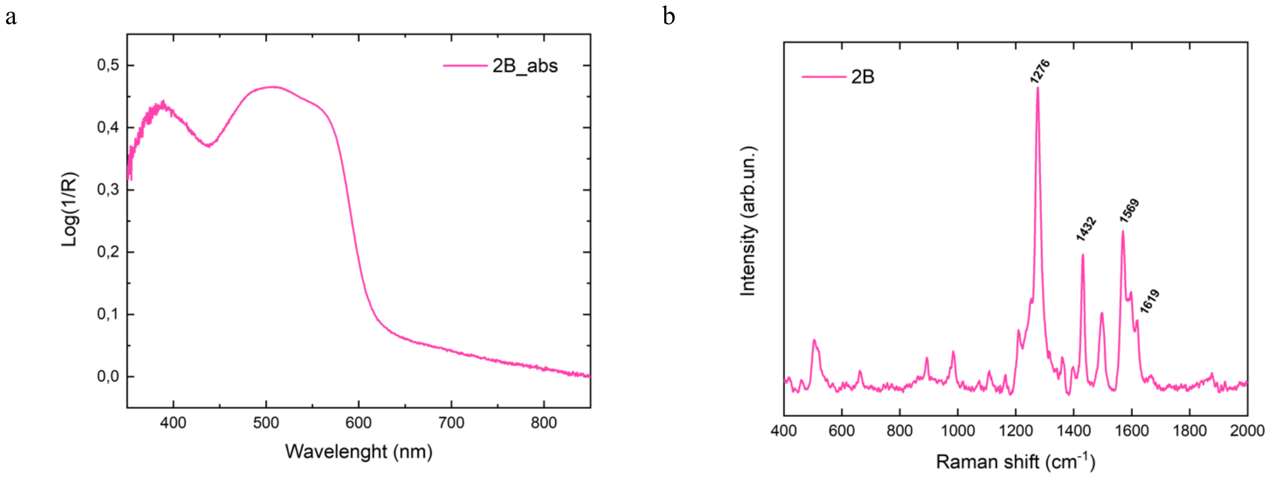

Fig. 8: FORS (a) and Raman (b) spectra of sample 2A.

***Prisente* by Carlo Ciussi (1990)**

The solitary sample (3D) obtained from the *Prisente* by Carlo Ciussi reveals a UV-Vis absorption spectrum (Fig. 9a) characterized by a pronounced peak at 430 nm and a wide-ranging shoulder between 440 and 480 nm. Regrettably, a definitive determination of the dye's composition was not possible based on the current state of literature research. Regarding the Raman spectrum of sample 3D, a notable broad band centred around 1600 cm^{-1} can be ascribed to the vibrational modes of the amide group (Berjot, Marx and Alix, 1987). Alternatively, the peaks identified at 1452 and 1342 cm^{-1} are attributable to azo aromatic groups. Through a meticulous comparison of the Raman spectra of synthetic dyes with dark colouration (such as brown, grey, and black) as documented in the literature (*SOPrano Spectral database*, 2023), an attempt was made to associate the dye with PBr42. Nonetheless, it is important to underscore that this proposed attribution stands as an initial conjecture, pending more rigorous chemical verification.

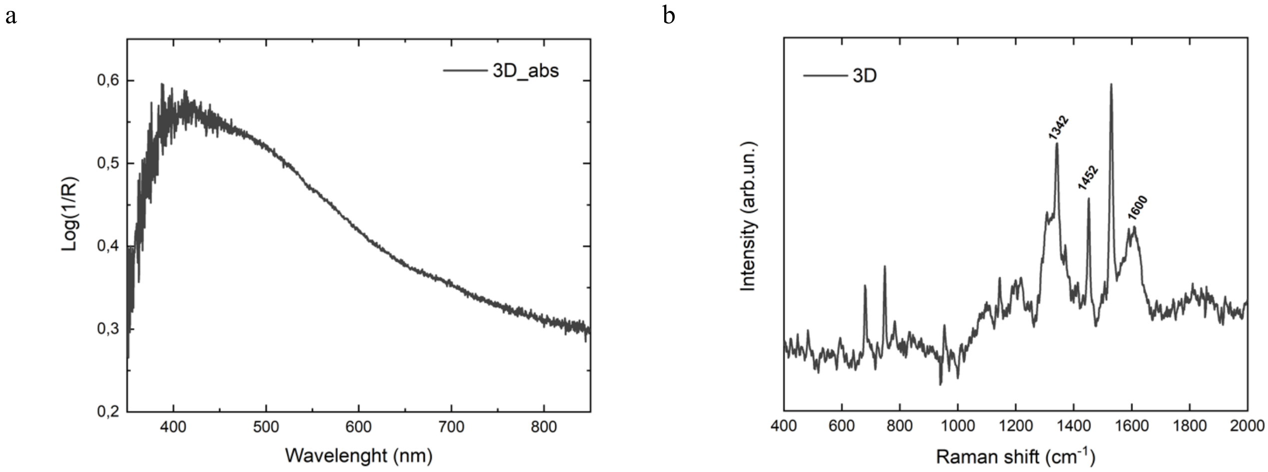

Fig. 9: FORS (a) and Raman (b) spectra of sample 3D

Conclusions

In the present work, spectroscopic data obtained from FORS and Raman analysis were successfully employed for the identification and characterization of synthetic dyes on six areas belonging to three different Sicilian *Prisenti.* Fiber Optic Reflectance Spectroscopy data served as a preliminary screening for the identification of the dyes. While micro-Raman spectra permitted hypothesizing a more precise identification of the dyes. In general, it was possible to obtain positive results with both techniques in terms of distinguishing the belonging molecular class. In some cases, the specific structure of the dye present was hypothesized through comparison with online spectral databases. It is clear form the results that further analysis, as for example HPLC-MS analysis, are needed to better comprehend the nature of this compounds.

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The iconic colors of Villa Reale in Monza

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Abstract

On the occasion of the Color Design Week (19-24 September 2022) at the Villa Reale in Monza, an in-depth study of the historical colors of the Villa was proposed. To this end, it was decided to analyze the rooms belonging to the three historical periods during which the most significant architectural and decorative changes were made: the Austrian period (1777-1780), the French period (1796-1818), and the Umbertino period (1860-1900). Preliminary visual chromatic measurements were carried out using the Natural Color System. This first survey brought to a rough selection of the measurement points for the subsequent instrumental measurements, which were performed using a spectrophotometer. Several rooms in the villa have been restored proposing the "original" colors and decorations, but it was decided to disregard them and measure the colors of surfaces that still retain the original colors. The color sampling was carried out directly on the original walls/ceilings or the internal layers of stratigraphies already present. The spectrophotometer-based measurements were carried out with the support of Konica Minolta. They were made in situ and provided suitable data for the subsequent chromatic analyses. This allowed to obtain a complete mapping of the main colors that characterize the three periods. In addition to the chromatic analysis, historical aspects were also studied and integrated, thanks to the contribution of the Royal Park Consortium and Villa di Monza. The documents concerning the restoration interventions carried out in the interiors (conserved in the archive of the Superintendence of Milan) were also consulted. Finally, it was decided to create summary color charts with only 5 colors per historical period: a work of extreme synthesis, obtained through an in-depth campaign of surveys and data analysis.

Keywords: Villa Reale in Monza, historical colors, color survey

Introduction

From September 21 to 24, 2022, the first edition of Color Design Week was held at the Villa Reale in Monza. The event curated by Francesca Valan and organized and coordinated by La Rivista del Colore, was dedicated to architects and designers (fig. 1,2 and 3).



Fig. 1,2, and 3 Data survey tour with architects and designers.

For the occasion, an in-depth study of the historical colors of the Villa was proposed. The historic analysis of the Villa was the starting point for a better understanding of the chronology of the Villa

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construction phases, and of the major changes that have occurred over the centuries. Along with the historian Corrado Beretta of Villa Real of Monza, it was decided to focus the analysis on the three periods during which the most significant architectural and decorative changes were made: Austrian period (1777-1780), French period (1796-1818) and Umbertine period (1860-1900).

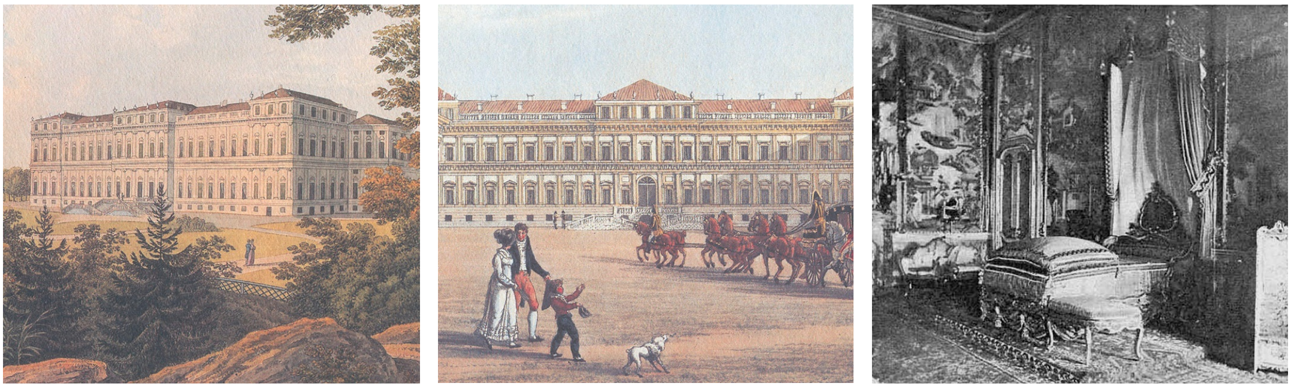

Fig. 4,5, and 6 Historical images of the three periods of the Villa. Photo credit fig. 4,5: Storia (2022). Photo credit fig. 6 By Treves - La Ilustracion artistica, Madrid, 27-8-1900 pag. 558

Visual Survey

The Villa has undergone numerous changes over the centuries and, in more recent years, even the real restoration of some internal rooms. However, there are some rooms, or some parts, which are to be considered "original" and have not undergone substantial changes or superficial reworkings. In some cases, these are wall finishes, or wall decorations, or tapestries, or even furniture or doors. The choice was to focus the analysis on the parts historically indicated as "original," not taking into consideration, for example, the restored rooms: although the restorations have as conservative lines of intervention as possible, the finishes were nevertheless restored and thus, albeit minimally, altered. Visual chromatic measurements were preliminarily carried out using NCS color cards (Fig.7,8,9)

Fig. 7,8, and 9 - Visual survey of Piermarini's original decorations.

This first survey allowed a rough selection of the places where instrumental measurements could subsequently be carried out. From this first investigation, the main characteristics of each historical period began to emerge. The Austrian Period (1977-1980) coincides with the construction of the building: a task assigned to the imperial architect Giuseppe Piermarini and completed in just three years. Piermarini created an exemplary building of neoclassical rationality adapted to the needs of a suburban reality. The stylistic essentiality of the building is due not only to precise aesthetic choices, but also to political reasons: the enlightened court of Vienna preferred to avoid an excessive display of

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wealth and power in an occupied country. Even the interiors comply with the principle of rationality and simplicity that characterizes the entire project.

The internal decoration was entrusted to the main masters of the newly founded Brera Academy, founded by archducal will in 1776. Stuccos and decorations of the reception rooms are due to the Ticino artist Giocondo Albertolli, frescoes and paintings to Giuseppe Levati and Giuliano Traballesi, floors and furniture to Giuseppe Maggiolini's workshop (de Giacomi, 1984; Rosa, 2009). The Royal Chapel was built between 1777 and 1780, based on a project by Piermarini, together with the Villa Reale of Monza (fig.10,11)

Fig 10,11 - Royal Chapel and its ceiling pattern. Photo credit fig. 10: Di Marco Opera propria, CC BY-SA

The French Period begins with the arrival of the Napoleonic armies in 1796, when the Villa underwent a period of decline until Napoleon's coronation in 1805 and the appointment as viceroy of his stepson Eugene de Beauharnais, who chose it as his summer residence.

The fall of Napoleon handed the Villa Reale back into the hands of the Austrians, who left it for a few years in a state of relative abandonment, until 1818 when the viceroy of Lombardy-Veneto Giuseppe Ranieri took possession of it. The Court Theater was designed in this period, in 1806, by the architect Canonica (fig.12,13). In a yearbook of 1838, the delightful theater hall was described as follows: "In a western wing, there is a graceful little theater like an arena... It is of a special good taste with paintings by Monticelli, a pupil of Appiani, and by various students from Sanquirico. In front of the stage protrudes a beautiful royal throne box flanked on the right by another for women, and on the left that for the court dignitaries" (de Giacomi, 1984; Rosa, 2009)

Fig. 12, 13 - Royal Court Theatre and its Ceiling Pattern. Photo credit fig. 12: Di Ale rivolta - Opera propria, CC BY-SA 4.0

When in 1860 the Lombardy -Veneto region was annexed to the State of Piedmont, the history of the Villa ended up inevitably, crossing with the fate of the Savoys. It became the privileged residence of Umberto I, thus returning to its original role as a holiday residence (Umbertine Period).

The sovereign entrusted the direction of the architect Achille Majnoni d'Intignano to decorate, restore and improve the Villa according to the taste of the time. It was therefore in those years that the Villa underwent a radical transformation in many of its parts (fig.14,15). The phase of profound change was abruptly interrupted with the assassination of King Umberto on 29 July 1900 in Monza. The new king Vittorio Emanuele III abandoned the Villa Reale, closed it and made transfer most of the furnishings to the Quirinale. In 1919 it was donated to the State Property Office (De Giacomi, 1984; Rosa, 2009).


Fig. 14,15 - Royal Apartment and its tapestry pattern. Photo credit fig. 14: Storia (2022) Reggia di Monza

Instrumental color measurements

The subsequent and in-depth color survey campaign was performed with the support of Konica Minolta. Dr. Roberto Pelanda carried out the instrumental measurements in situ (fig. 16,17). This allowed to obtain a complete mapping of the main colors that characterize the three areas. Table I II, III show the sampling points, divided by period and by environment. As one can see, all the gripping points were made on "historical" finishes or on stratigraphy that reported the "original" state. The collected data were subsequently processed, to extract the codes in the NCS color system. Each sampling has different colors, because the surfaces are not homogeneous and, in some points, not in an excellent state of conservation. In view of this chromatic data collection, we wanted to summarize what was found by means of synthetic chromatic charts: specifically, a chromatic chart for each period, made up of only 5 colors. This choice was made in view of the desire to make the results of the work easily disseminated to the wider public: for example, in the form of gadgets, bookmarks, postcards, that is, in an easily usable format. The complete results of the work will instead be made available to the historians of the Villa Reale in Monza and to anyone wishing to have a deeper and wider insight.


Fig. 16,17 - Instrumental color measurements.

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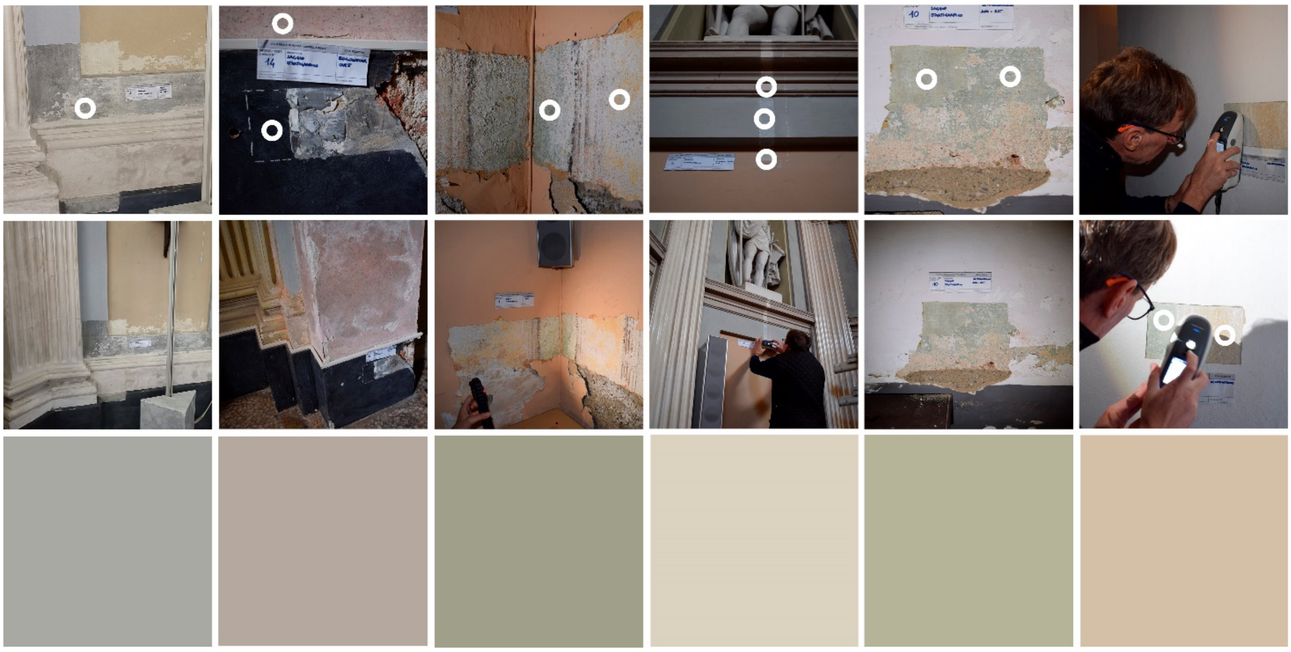
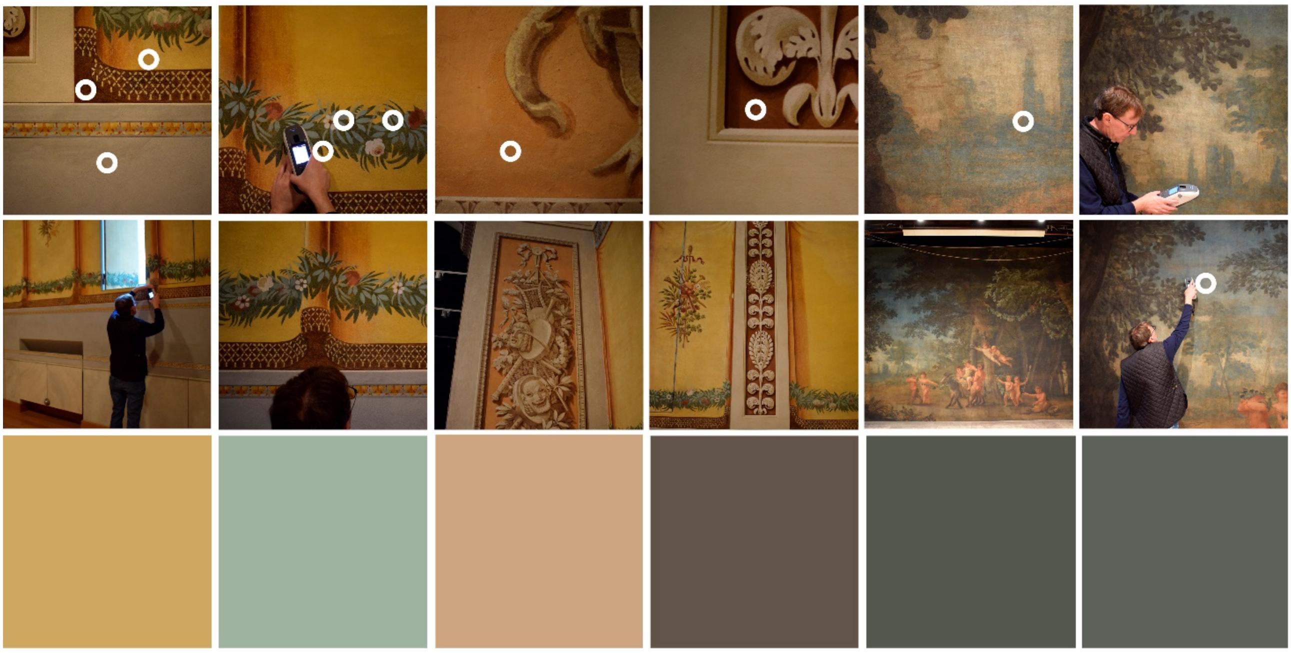


3_Clear Point	5_Base Plaster	8_Green	9_Yellow Niche Interior	11_Left Green	16_Right Ochre
Lab - 68.48/-1.28/3.38	Lab - 51.36/-0.21/4.3	Lab - 65.5/-2.87/12.41	Lab - 84.63/0.24/11.81	Lab - 72.86/-2.42/14.22	Lab - 78.54/4.11/15.07
Munsell- 3,8GY 6.7/0.46	Munsell- 5,6Y 4.99/ 0.6	Munsell- 1,2GY 6.42/1.7	Munsell- 4,2Y 8.38/ 1.51	Munsell- 9,8Y 7.17/ 1.86	Munsell- 0,1Y 7.77/ 2.37

Table I - Points of measurement in the Royal Chapel with LAB and Munsell codes.



35_"Tendori" Yellow	38_Light Green Festive	40_Orange Background Stage decoration	43_Bottom Pillar Dark	44_Stage Scene Blue	45_Stage Sky Scene
Lab - 71.48/10.65/41.16	Lab - 71.14/-9.42/5.92	Lab-70.92/12.32/26.07	Lab - 37.29/5.62/7.32	Lab - 36.56/-3.55/5.09	Lab - 40.73/-3.96/4.35
Munsell- 1,1Y 7.12/ 6.52	Munsell- 2,6G 6.97/ 1.77	Munsell- 7,5YR 7.02/4.79	Munsell- 5,2YR 3.65/1.49	Munsell- 6,7GY 3.57/1.15	Munsell- 8,7GY 3.96/ 1.1

Table II - point of measurement in the Royal Court Theatre with LAB and Munsell codes.

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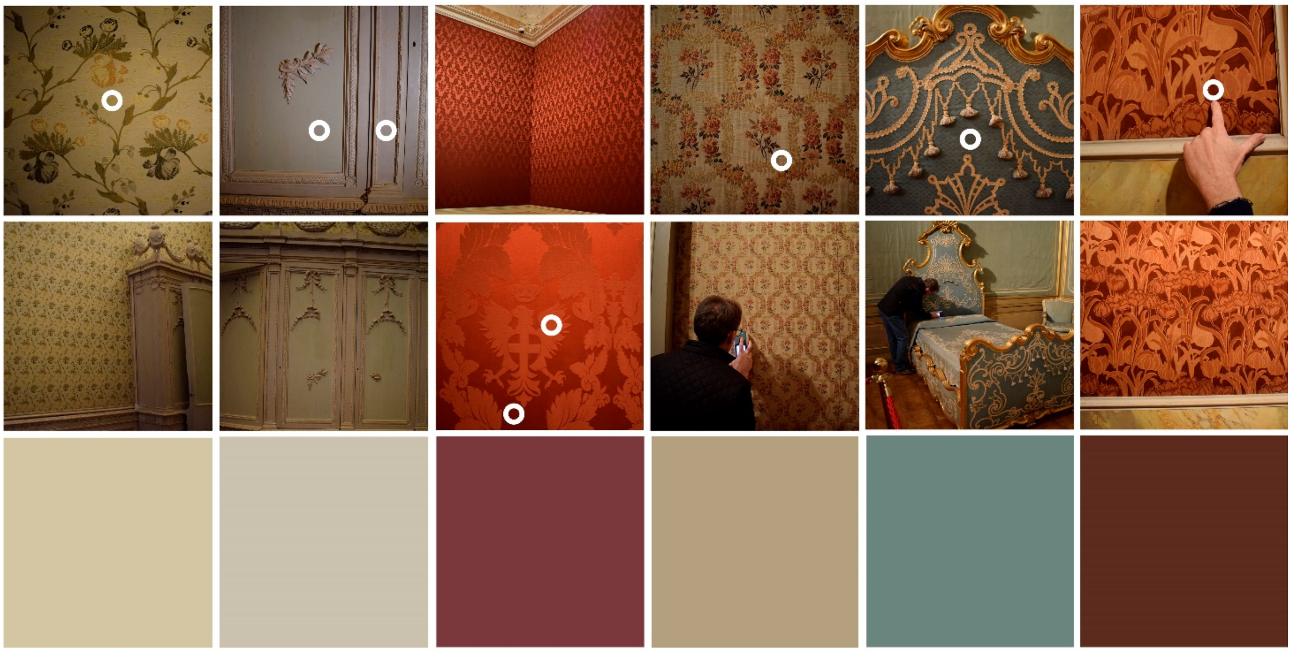

18_Bottom Tapestry Lab - 80.38/0.98/18.57 Munsell- 3,7Y 7.96/ 2.56	19_Wardrobe Bottom Pillar Lab - 78.92/1.11/11.49 Munsell- 2,1Y 7.79/ 1.58	23_Opaque red Upholstery Lab - 33.3/29.92/10.9 Munsell- 4,5R 3.3/ 6.54	47_Back Upholstery Lab - 66.94/3.73/20.51 Munsell- 1,5Y 6.59/ 3.07	48_Bed Headboard Lab - 52.87/-9.51/0.39 Munsell- 3,9BG 5.11/1.7	49_Back Upholstery Red Lab- 24.33/22.71/20.46 Munsell- 2,2YR 2.43/5.68

Table III - point of measurement in the Royal Apartment with LAB and Munsell codes.

Processing of the color charts

The elaboration phase of the chromatic folders was particularly complex, due to the high-level synthesis that had been established in the initial requirements. In order to compare the data collected and to associate the historical names to the colors detected, we also relied on historical-archival research (fig.18,19,20 and 21). We consulted the documents concerning the latest restoration interventions carried out in the interior of the Villa and kept in the archive of the Superintendence of Archaeology, Fine Arts and Landscape in Corso Magenta in Milan. The diagnostic investigations carried out prior to the recorded interventions were particularly useful: for example, the sections with highlighted layers of color with the respective characterization of the materials through FT-IR investigations. This allowed the individual pigments originally used to be identified (Lazzari, 2011; Lucchini, 1999; Terregni, 2018).

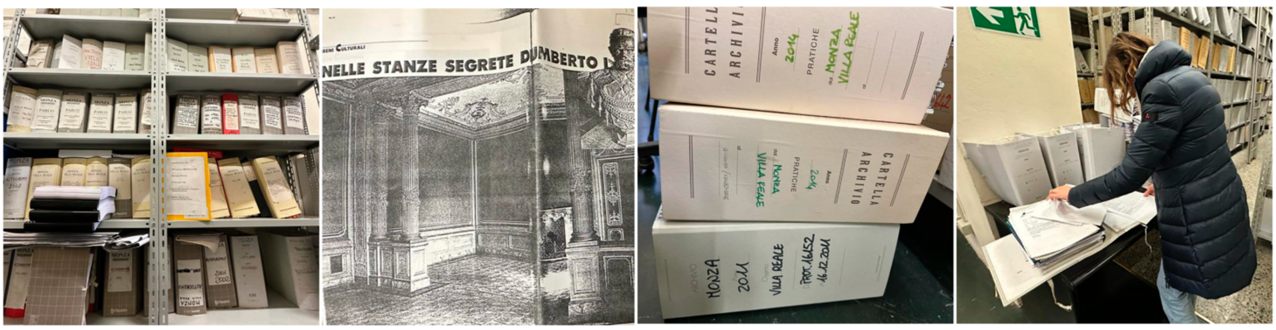

Fig.18,19, 20 and 21 Research of historical data at the Sovraintendenza of Milan.

A separate search was carried out for the nomenclatures given to the colors detected and proposed in the color charts (fig.22). Also, from this point of view, the historical reports of the projects were very useful, in addition to the historical research already mentioned above. In fact, from these it was

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possible to extrapolate the names that were originally used to indicate particular colors. Conversely, when there was no direct reference to a specific color, an attempt was made to identify to the original materials described in the manuscripts, similar to the colors proposed in the color charts.

Fig. 22 – First proposal for color charts of the three historical periods.

Conclusion

The paper has presented an in-depth study of the historical colors of the Villa Reale in Monza, proposed on the occasion of the Color design week (21-22 September, 2023, Villa reale di Monza). In the analysis, it was decided to analyze the rooms belonging to the three historical periods during which the most significant architectural and decorative changes were made: the Austrian period (1777-1780), the French period (1796-1818) and the Umbertine period (1860-1900). Preliminary visual chromatic measurements were carried out using the Natural Color System. However, the research did not want to arrive at establishing an exhaustive list of color codes (which is almost impossible in the context of historical colors). Rather, it aimed at raising awareness of shades that today are difficult to perceive because they are "immersed" and hidden among all the changes made over time. The results of the research were summarized by means of synthetic chromatic charts: specifically, a chromatic chart for each period, made up of only 5 colors. This choice was made to disseminate the results of the work to the wider public: for example, in the form of gadgets, bookmarks, postcards. The complete results of the work will instead be made available to the historians of the Villa Reale in Monza and to anyone wishing to have a deeper and wider insight.

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The architectural lexicon of the surfaces of the Post-Unification Italian cities

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Abstract

The research that is intended to show starts from the studies of the Polytechnic of Bari focused on the architectural lexicon of the post-unification building of the cities of the "Land of Bari". The research immediately highlighted how the linguistic and formal choices of the architectural surfaces of the historic cities are inseparable from the national cultural context of reference. Furthermore, it should be highlighted that the architectures belonging to the period from the end of the eighteenth century to the Italian Unification are very emblematic of a desire to declare a sense of belonging of the client to a cultural and political area, choosing architectural forms and a formal language specific to a territory or a specific political power, sometimes even with more or less explicit extra-territorial references. In the post-unification period, this form of expression of belonging, by the owners and clients, acquires an even greater value, both in regionalist terms and in terms of political and cultural membership.

It is needed to add, and often in an artfully instrumental way, the Risorgimental - post Illuministic approach of the desire to declare a form of " honesty of thearchitecture" in the manifestation of "true" materials in "true" construction techniques. This is a fair derivation of the Renaissance research well declined by artists such as Antonio da Sangallo the Younger and Baldassarre Peruzzi (among others), but in the definition of the Umbertinian architectural program, could enters into conflict with the formulation of the "meaning" of the original architectural grapheme.

It is precisely in this revision of the relationship between "material" and "meaning" of the architectural "grapheme" that the color takes on a distinctive role. In fact, the post-Illuminism desire to declare (through the colors) the honesty of the constituent material of the architectural surfaces entails the loss of the information that those elements of language assumed precisely through their chromatic "consistency" on the surfaces.

To the theme of the relationship between "material" and "meaning" introduced by Paolo Marconi in the 1990s in the field of architectural restoration is linked the theme of the colors of architectural surfaces and the related identity meaning. Far from being exhausted today, it is linked too the today's issues of the recovery of non-preserved historic building surfaces, through public grant procedures, where these interventions does not have suitable safeguarding tools, neither in the administrative management of authorizations, nor in the guarantee of technical-scientific training of operators.

Keywords: Architectural language and structure; color and significance; material and architectural significance.

Introduction

Starting from the conception of the architecture of the palace facades of Renaissance and then neoclassical period, a convention was consolidated in the dialectical relationship between formal language, structure and actual constituent material. This convention strongly recalls the functional-formal nexus of the classical language of architecture.

The study of the authors of the Renaissance is strongly aimed at the interpretative survey of the artworks of the past with the intention of bring out a noble antecedent to trace back the feeling of the representative architecture designed by them.

When the architecture for the palace facades, with the greatest exponents of art and culture of the time, Leon Battista Alberti and then Donato Bramante, commits the hybris of the use of architectural order on public facades, it is opened up a fundamental theme: in the conception of classical Templar architecture, the use of order (the free column) is linked to the cohesion of the iconic value with the load-bearing function, while the function of separating the physical space is delegated to the back wall, originally without any order.

It is not inappropriate to specify that the interpretative model of Renaissance architecture we have is made through the legacy of the formulation of the French treatise writers of the eighteenth century conveyed by the Academies of Fine Arts and then by the schools of architecture.

It comes out that the iconic-tectonic reference model the contemporary age use to reads the forms of architecture from the Renaissance to the modern age is strongly linked precisely to the determinist ideology of the iconography of the trilithic system and to the formal honesty in the architectural declaration of the coincidence between the trilithon and the stetic system. It should also be highlighted how the ideology of the "Mitteleurope" style according to the Semper school suggests another different model for reading the work of the ancients which places the emphasis on the textures of the surfaces use for the confinement and division of space rather than on the emphasis of the trilithic system.

The finding for a language of post-unification cities

The great transformations of the urban structures of the historic cities and the foundation of the new districts of the cities by Risorgimentao period derive directly from a new concept of the community, a new type of economy and a consequent strong urbanization.

This new social convention cannot happen without a very strong political imprint. In the Italian case, by the widespread diffusion of the new image of the new unitary state of the new kingdom of Italy

The new transformed city, like the new districts must therefore respond to criteria of urban functionality, compliance with new social needs, the increased impact of a much greater number of users of urban structures and new performance expectations, at least in terms of public hygiene: with the expansion of road width, with great demolitions (or in some late cases "thinning" out) and, where not already existing as often happens in southern Italy, with the construction of the sewage system.

This heavy social and political transformation of cities needs to be equipped with a representative and recognizable architectural image.

The architects of Risorgimento inherit an Italy that derives locally from various dominations and kingdoms, the last to fall is the Papal State, which built (in eighteen hundred years) an ideology of alleged holy direct derivation from the great antecedent of cultural unification of the entire Europe of the Roman Empire.

The population also still retains a strong memory of the occupations and interferences of the great European powers, first of all the French occupation of Rome, first against the pontifical state with Napoleon and then in support of it with Louis Napoleon III.

The Napoleonic ideology, heir of the revolutionary principles, left a radical restoration of the concept of social law throughout the whole Europe. In Italy and in Rome in particular, the restorations and reconstructions of the Via Sacra under the Arch of Titus and the Colosseum cannot fail to recall the great antecedent of the restoration of social rights desired by the Flavian dynasty after the Neronian empire. And the mark they leave is indelible from the monuments of antiquity in their eternal longevity.

Not being able to reconstruct the image of the united Italy under the aegida of the Roman legacy so abused by today's rivals on the political scene, they had to search another model of architectural language, passing through the now consolidated recognition of the concept of Style resulting from academic training in whole europe.

The new city will therefore have to refer to the models of the values of social law and the values of the individual being which is the basis of society, to the reborn concept of the city as a healthy organism and a place of sharing social and cultural life.

The principles of the Renaissance can be recognized in these identity values. When the artists of the Italian peninsula, from Florence to Milan, Rome, Venice, Naples and Palermo over the course of a century reinvent the very concept of architecture.

this is the start of a long period of survey activities carried on the whole italian area and in particular on the via Appia monuments or in the "campo vaccino" of Rome (as the area of the Forum of the Republican era was then called).

Bramante, Giuliano and Antonio da Sangallo, like all their students and the students of them until the Baroque age, invented a new way of studying the art of building on the basis of the surveys of the artwork of the ancients, interpreting their technical and tectonic mechanisms, placing the foundations for today's disciplines not only of surveying and philological study, but also of the method of learning composition, technology and the science and technique of construction.

“Order” and “background”

With Bramante's invention of taking up the classical Order on the architectural surfaces of palaces on superimposed levels, already pioneered by Alberti (with Rossellino) for Giovanni Rucellai's palace in Florence [1446-1451], a new season opens for the formal lexicon of residential architecture.

In both works, however, it should be noted that the two authors preserve the signature of the isodome ashlars on the entire surface of the building (between the lisens) for the three levels.

Moreover, the previous tradition, in both contexts, reported infinite examples of replicas of construction textures re-proposed on graffitied plasters or paintings regardless of the actual method of construction, and used instead in an allegorical and decorative purpose.

For the bases, following a long-standing experience capable of preserving the symbolic image of the *opus quadratum*, and of construction techniques in general, the sixteenth-century authors tirelessly resorted to citing the isodomic work as the masonry texture par excellence, but merely reduced to a single covering of slabs (if not actually made of mortar) in place of the stone work for the entire thickness.

The complex artifice of reference to the ancient architecture construction and form becomes more complicated with the insertion of order on the upper floors, as the original scenic reference, constituted by the classical temple, does not provide examples of openings like windows , nor the superposition of several floors (if not in some exceptional cases).

Therefore, Renaissance architecture must seek the model for the framework of order on multiple registers starting from civil Roman architecture, Silla's Tabularium, and theatres/amphitheatres. These in fact constitute the undisputed reference for the Loggia delle Benedizioni of San Marco, as for the courtyard of the palace in Venice (with the needed variations), and then for all the following public loggias.

While in the Tabularium or in the Flavian Amphitheater the floor was placed at the top of the entablature and the bases of the columns rested there, on the same level of the floor, in the Blessing Loggia this does not happen: rather the main floor faces with a basement stylobate resting on the entablature of the order lower which constitutes the parapet for the use of the loggia, leaving the floor at the level of the ending frame. Formally, the inclusion of a stylobate to support the order does not appear to be erroneous, however this creates an "embarrassment" in the identification of the level of the main floor on the external façade: where the celebrant of the classical temple steps on the stylobate, where rests the columns that support the temple too, in the Blessing Loggia, the Pontiff places his foot lower than the stylobate, at the level of the frame, partially hidden from the view of the faithful by the same stylobate on which the order of semi-columns continues to rest. That interrupting the symbolic strength of the construction in which the colonnade that physically supports the structure belongs to the same share as the celebrant who supports it spiritually.

The same "lexical element" in the palace architecture of the Cancelleria or Palazzo Caprini (both by Bramante in the first decade of sixteenth century) is not equally problematic, given the loss of the liturgical function: in this case, it does not seem strange how the "weight" of the order continues to weigh down, crossing the stylobate which thickens into a plinth, until it unloads on the frame corresponding to the internal flooring; and the same stylobate serves as a support for the aedicule windows, using the same “plinth” (in Palazzo Caprini pierced by a balustrade)

The theme of the lexicon of architectural surfaces until now linked to the formal character is further articulated in the use of finishing materials, where the isodomic stone construction is replaced by a facing in slabs (or blocks) whose constituent elements do not correspond to the size of the actual ones or of the order in relief on the background surface.

Clients economical reasons, in many sixteenth-century architecture, induce to also resort to the use of stucco and plaster in place of stone slab facings. Thus we begin to articulate a new level of mediation in the lexicon of surfaces: what bears the "architectural meaning" is no longer the wall structure, it is no longer even the material consistency of the surface, but only its citation, also

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through simple chromatism of plastered portions, sometimes marked by a single scratch in the plaster.

In the last years of the 19th century and the beginning of the 20th century, the belief in the need to declare the "true" material essence through the colours, favoring the colors of the terrigenous materials for the mortars (plasters, stuccos...) and leaving only the stone the visible material value: Andrea Busiri Vici himself painted the precious Palazzo Pamphilj at the Circo Agonale in a uniform “Turin” ocher colour. The Quirinale palaces, Palazzo Chigi-Odescalchi and Palazzo Venezia were covered in dyes ranging from red to ochre-orange. These colors probably also served the typological and formal unification in those years, at least in relation to the buildings symbolizing power, to the new regime which imported, together with the colours, the "taste", the chromatic tradition and the Piedmontese construction companies.

Only the restorations of recent decades have allowed a more careful understanding of the chromatic meaning of the surfaces. Bringing back to view the historical colours, the bricks, whether they were ground or not, depending on whether they had to be exposed or protected by plaster, the fake marbles and the light blue and ashy dyes of pontifical Rome.

Precisely to these colours, Renaissance architecture entrusted the interpretation of the architectural form, starting from the Raphaelesque Palazzo Vidoni Cappello which features, according to the model of Palazzo Caprini, twin semi-columns in "stone-coloured" stucco, placed on travertine cubes, on background which probably had to appear in a brick curtain, ending with the exedra of Gaetano Koch where on the travertine base surface faux travertine plastered façades stand out, with the imitation of the isodomic work, in the scratching of a hypothetical slab and in the imitation of alveolizations for horizontal striations as recommended to optimize the compressive strength of the material.

The syntax of the traditional tectonic party is reread in the dialectical relationship between elements of the order and "background", on distinct planes, which is flanked by a system of wall textures which instead defines the elements actually constituting the load-bearing system. In this sense, Peruzzi's intervention at the Villa Farnesina Chigi is particularly curious where he stands out from the plastered backgrounds the pilasters in relief in exposed brick (a material usually dedicated to the background of walls), and indeed highlights the contradiction between the formal register of the iteration of the trilithon of the order on the two registers of the facade, inserting in the thickness of the corner pilaster some interlocking blocks of gray stone to constitute a sort of cantonal in strong contrast with plastered walls and bricks, but whose interlocking depth is equivalent to the width of the pilaster itself, hybridizing and at the same time denying in a clever game, within the same element, the lexicon of tectonics for linked walls and the lexicon of the trilithic structure.

The rediscovery of the “texture”

Another "face" of Renaissance research also deserves to be underlined, which does not forget the load-bearing value of masonry: proof of this is the Sangallesque comb cantonals as well as Baldassarre Peruzzi's experimentation in the hybridization of the comb cantonal in the corner flat pilasters of the Farnesina Chigi in Via della Lungara (Rome - Today no longer visible after a restoration which aimed to hide this solution with a dull covering.

It is worth mentioning the parallelism which also sees the architects of the Italian post-unification period experimenting with the search for a lexicon deriving from wall textures, such as Quadrio Pirani in the public housing of Testaccio and San Saba who inserts evident elements of taste into the high pilasters textiles, such as tassels and stylized hangings and highlights the textural quality of the alaterial work. Probably not forgetful of Gottfried Semper's studies.

A partially different path is that of the young Piacentini, before the fascist experience, when in the "Corso" Cinema project in Piazza San Lorenzo in Lucina, he indulges in secessionist quotations aimed at emphasizing a new young concept of architecture for a new unprecedented function.

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6. Color and Environment

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Chromatic Revolution in Urban Landscapes: A Perspective from New Urbanisms of Colour

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Abstract
Colour in the design of urban spaces, including public art, urban design and landscaping, has undergone unprecedented changes since the new millennium. In recent years, the application of bright, high-chroma colours, namely saturated colours, has become increasingly popular in the design of urban spaces. This trend has been particularly evident on social media and design websites. This paper stems from my completed PhD research, which sought to offer a fresh understanding of this trend and a systematic approach to analysing colour design in contemporary urban landscapes, with a focus on the social dimension of colour. Urbanisms of Colour represent a relatively recent perspective for examining environmental colour. Its objective is to demonstrate the connection between the social and the physical (colour) and to comprehend the change and impact of colour based on its relationship with urban issues. Drawing upon urbanism theory, this research introduces a conceptual model of urbanisms of colour to steer the investigation. With the assistance of this specialised lens, this paper will delve into noteworthy instances from the past two decades, illustrating how shifts in urbanism have resulted in radical changes in colour design and a preference for saturated colours in urban landscapes. Through these cases, the paper aims to demonstrate a reinforced connection between colour and urbanism, especially with the progress of globalisation, the growth of the digital market, and the prevalence of social media, which have all contributed to strengthening the link between colour and urbanism.

Keywords: colour, environmental colour, urbanisms of colour, urban and landscape design

Introduction

In the built environments, colour design is often approached with a somewhat conservative mindset. Neutral colours and those intrinsic to materials take precedence, while brighter and more vibrant hues—referred to as saturated colours herein—are relatively less common in environmental colour design. Apart from vivid colours from vegetation, the dominance of natural and neutral colours in landscape design has not faced challenges till recent years (Engler, 2022). A sudden change in the trend of applying saturated colours and ways of using colours in urban spaces has occurred in the past two decades. Contrasted with the prevailing grey or neutral backdrop of modern cities, these expressive colour designs make urban and landscape designs stand out. This sudden appearance of these bold and bright hues has taken us by surprise, popping up in unexpected places and adding an exciting new dimension to urban life. Even if this explosion of saturated colours has not arrived in all cities and reaches everyone in person, for people who enjoy social media, it is hard to not encounter the countless images on different platforms with people smiling and posing in front of colourful spots throughout cities.

In environmental colour design, saturated colours have typically not been the initial preference in most Western societies, with only a few exceptions. The neutral and unsaturated colour palette prevalent in our environment may be attributed to various factors. Over an extended period, building materials have been constrained in terms of bright and primary colour options, primarily due to technological limitations and an underdeveloped global trade network (Porter and Mikellides, 2009). In addition, Batchelor (2000) argues that there is a cultural complex concerning vibrant colours. He defines persistent underestimation of colour and a reluctance to use it (especially in architecture) as Chromophobia, which may have largely contributed to the prevalence of grey and neutrally tinted environments. As discovered by (Lenclos and Lenclos, 1999), vibrant environmental colour palettes are likely to appear on vernacular buildings in regions that have specific geological features. Jean-Philippe Lenclos (Lenclos and Lenclos, 1999) argues that the preference for bright colours is a synthetic outcome that ‘grows’ from the local conditions, including climate, geology, light, local materials, sociocultural behaviours and traditions.

Landscape and urban spaces seemed to be under the similar influence of architectural environments in terms of colour. Dominated by the appreciation of naturalism and the availability of local materials, colour is often a subordinate concern in landscape architecture (Engler, 2022). It seems to be widely accepted that the colours and colour scheme inherent in materials, usually neutrals and earth tones, are perfect and do not need any changes (Boeschenstein, 1986). Saturated and artificial colours began to show up in landscape design at the beginning of the 20th century. Despite several landscape architects explored bright colours in designs and built up their styles on them, such as Guevrekian, Bernard Tschumi and Martha Schwartz, saturated colour has not been a conventional technique in most designers’ toolboxes (Engler, 2022, Schwartz et al., 1997). The use of bold artificial colours, at least before the 2000s, was considered a personal style or signature design of prominent designers in both landscape and architecture (Caivano, 2006; Schwartz et al., 1997).

Considering the general preference for environmental colour as well as the conventions of using colours in landscape designs, the sudden emergence of saturated colours observed in worldwide urban spaces indeed requires the attention of both colour and urban researchers. Over five years of research conducted by the author has systematically examined the upward trend of saturated colours in urban and landscape designs by collecting data from 692 projects characterised by saturated hues between 2000 and 2019, regardless of the their location. One of the key objectives of the research is to provide a perspective to understand the dramatic changes concerning the rising favour of saturated colours in the global contemporary urban landscapes. By examining established colour theories and drawing support from data collected in design projects, it is discovered that the connection between colour and urban issues represents a significant advancement in our understanding of colour within urban environments. Like the widely recognised theory proposed by Dominique Lenclos and Jean-Philippe Lenclos (1999) – that being the "geography of colour", which describes the fundamental link between environmental colour and geographical factors, herein termed as "urbanisms of colour," this conceptual framework aspires to elaborate the dynamics of environmental colour, particularly its evolution shaped by its intricate interrelation with urbanism. This paper aims to introduce this concept, and by analysing representative cases, it seeks to elucidate the growing adoption of vivid colours in urban and landscape design through this particular perspective. This paper intends to demonstrate that we have entered an era characterised by new urban colour dynamics, where colour assumes a more substantial role in our urban environment.

Urbanisms of Colour

Urbanisms of colour is a concept introduced by Gareth Doherty about a decade ago in the book New Geographies 03: Urbanisms of Color, which provided a lens for understanding colour in urban environments. While previous studies on colour may have considered colour and its influence in urban settings (e.g., Boeri, 2017; Smith, 1970), Doherty (2011) was the first to propose this concept and to address the social dimension of colour. With few exceptions, discussions of colour have managed to be avoided or merely mentioned in the urban literature (Doherty, 2011). Before this concept, and even today, when it comes to environmental colour design in both design practice and colour literature, architects and researchers refer to two main guidelines: colour harmony and colour function, based on colour theory and Lenclos and Lenclos's (1999) ‘the geography of colour’ (e.g., Porter and Mikellides, 2009; McLachlan, 2013). Nevertheless, both traditional colour theory

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and the concept of the geography of colour focus on the conventional practice of colour. From current perspectives, there are no notable findings that can address the abrupt change in the acceptance of saturated colour and experimental ways of using colour in urban and landscape design.

From this perspective, the theory of geography of colour should be considered as a first step in establishing the link between the physical and the social. As the findings of the geography of colour show, the regional colour palette is shaped not only by climate, geology and local materials but also by sociocultural behaviours and traditions (Lenclos and Lenclos, 1999). The geography of colour, however, primarily explores how past and traditional understandings and usages of colour have influenced the chromatic characteristics of living environments, whereas urbanisms of colour introduce the discussion of colour into the present, highlighting ongoing changes.

To develop the concept of urbanisms of colour as a framework to guide the investigation of the emerging trend of saturated colours in urban and landscapes, the author refers to urbanism theories developed by Louis Wirth, who was the first to systematically define the concept of urbanism and to distinguish it from urbanisation. According to Wirth (1938), urbanism is the urban mode of life, a way of life, happening in an area with particular physical, demographic, social, cultural and economic settings, a city. In general, urbanism relates to the processes and outcomes of how urban inhabitants interact with factors and relations in urban settings, whether they are physical or social.

Referring to Louis Wirth's theory, incorporating colour into the discourse on urbanism requires examining both urban settings, which serve as a stage, and the actors (colour and urban issues), as well as the intricate relationship between them. In this study, the concept of "urbanisms of colour" includes two components: two components: a state of urbanism, which represents the relevant urban context where the study of colour occurs, and the collection of various interrelationships between colour and urbanism. Lifestyles in metropolitan areas differ significantly from those in small towns, and even within the same location, urbanism in the 1960s was distinct from today's urban landscape. The world is rapidly changing due to globalisation, industrialisation, and technological advancements, leading to fundamental shifts in urbanism (Anderson, 1959). Urbanism evolves with society, and although this evolution may not directly involve colour, colour-related decisions are influenced to a significant extent. Limitations in technology and underdeveloped global trade meant that bright and primary colours were expensive and therefore not common in European buildings in the early 19th century (Porter and Mikellides, 2009). As a result, global popularity regarding the application of bright paint to urban surfaces as a fast and economical practice would only be possible when pigments could become mass-produced and widely available through globalisation (Boeri, 2017; McMorrough, 2006). Therefore, there is a pressing need for studies of colour to be contextualised, especially when exploring the link between colour and urbanism. The state of urbanism would inevitably have a significant impact on the interrelationships between colour and urbanism.

The second part of urbanisms of colour refers to the different types of interrelationships that that can exist between colour and urbanism. Wirth (1938) argues that urbanism can be approached empirically from three interrelated perspectives, these being the physical structure and foundation, associated systems of social nodes and connections, and, finally, sets of attitudes and ideas, modes of thinking and acting. According to his theory, the present study categorises interrelationships between colour and urbanism into three types. The essential connection lies in how colour directs or influences the use of urban spaces, such as specific road signs and dividing different functional sections. This connection lies in the direct interaction between people and colour within the specific physical environment. The second connection is between colour and social factors and relationships beyond this physical space. For instance, in chromatic interventions, physical changes (saturated colours) are set in motion to trigger social changes, including community engagement and providing economic opportunities (Boeri, 2017; Flecha et al., 2017). The final but not yet explored link is between colour and urban modes of thinking and behaving namely lifestyles. Although the last connection has not been addressed, examples such as Pink Street highlight the associations between colour and changes in lifestyle (Nofre et al., 2018). Colour contributes to the utilisation of urban space and, simultaneously, is also shaped by the demands in urban environments.

With these findings in mind, this study visualises the conceptual model of urbanisms of colour (see Figure 1.1) and uses this model to guide the exploration of environmental colour through the lens of urbanisms of colour.

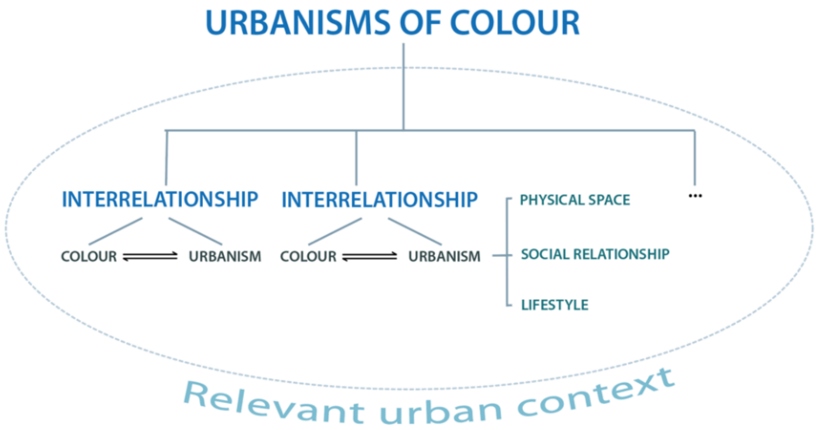


Fig. 1.1 - The conceptual model of urbanisms of colour developed in this research. Diagram by Beichen Yu.

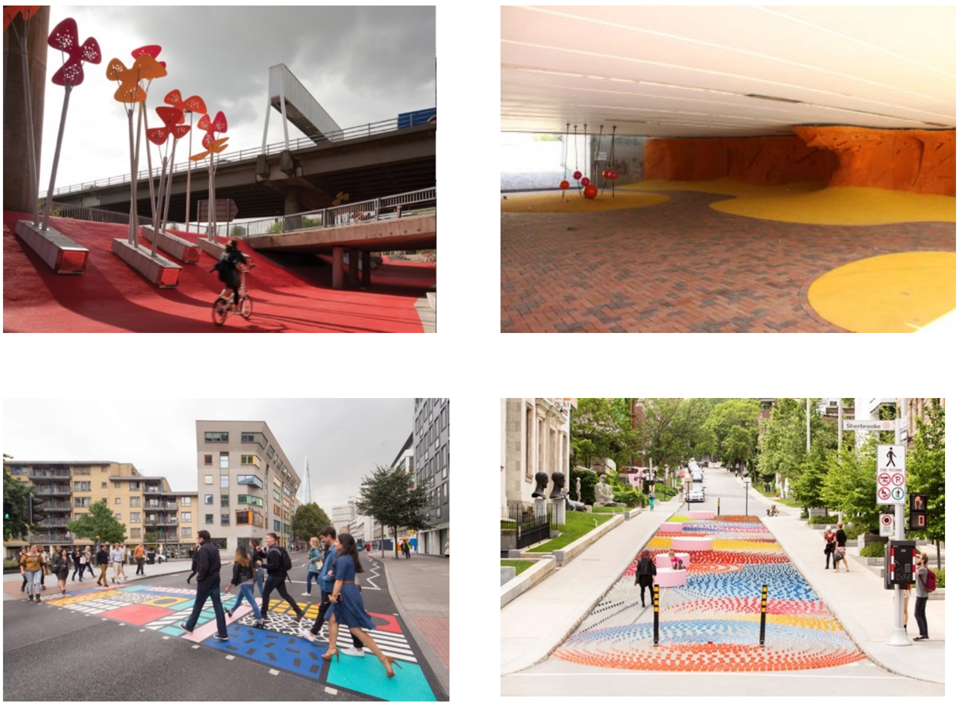
New Urbanisms of colour in urban and landscape design

This study collected 692 projects featuring saturated colours from around the world between 2000 and 2019 in order to describe the emerging trend of saturated colours in urban and landscape design. The concept of urbanisms of colour serves as a valuable tool for interpreting the shifts in colour design and the overarching characteristics of this trend. For instance, in the preliminary phase of this study, the author revealed that saturated colour palettes from various regions, such as Europe and Asia, exhibit more similarities than differences, contrary to what might be expected based on their geographical locations (Yu and Simon, 2022). This discovery, which challenges the rigid connection between environmental colour and geographical factors identified in the "geography of colour" (Lenclos and Lenclos, 1999), can be explained by the concept of urbanisms of colour. Rapid technological advancements and global trade have liberated colour expressions from the constraints of local materials and costly pigments. Vibrant colours are now possible with accessible materials like rubber granules, artificial pigments, PVC panels, or tinted glass (Yu and Simon, 2022). The changes that occurred in the urban context not only laid the foundation for shifts in colour design but also influenced the motivations behind these changes. A previous study by the author revealed that almost two-thirds of urban and landscape designs (431 out of 692) incorporated saturated colours for branding purposes. These colours were intended to attract the growing international online audience, spurred by the surge in social media (Yu, 2023). The influence of cultural globalisation and the branding intentions associated with saturated colours contribute to a more global and uniform expression of colour.

Exploring this phenomenon from an urban perspective reveals a promising avenue for understanding the radical colour changes. Building on the conceptual model of urbanisms of colour, this paper examines some notable examples to highlight the complex interrelationship between colour expression and urbanism in urban and landscape design. Through these cases, the research aims to demonstrate a strengthened connection between environmental colour and urbanism, which may account for the rapid growth of saturated colours, heralding the era of the new urbanisms of colour.

Before this observed emerging trend of vibrant hues in urban and landscape designs, saturated colours were found to serve functional purposes in urban spaces, such as wayfinding, defining sections, and providing an appropriate atmosphere. This study identified conventional usage of saturated colours in urban spaces, including playgrounds and traffic areas. Nevertheless, with the dramatic changes in the urban context, corresponding changes have occurred in the way and the intentions of using saturated colours in designs.

Brightening monotonous and unpleasant underpasses or reminding people of road safety were the major purposes of incorporating saturated colours in traffic environments. However, with the changing demands of urban spaces triggered by the transformation of urbanism, the use of colour in urban and landscape designs changes accordingly. As demonstrated in the cases of Garscube Landscape Link and the 'entree G' playground at the underpass of a road (see Figure 1.2a and 1.2b), vibrant colours convey interpersonal messages to pedestrians and cyclists, encouraging the use of these spaces for urban life. In these two cases, saturated colours were introduced primarily for the functions within the physical spaces, with a straightforward use of colour to identify the road and sections.



(c) (d)

Figure 1.2 - (a) Phoenix Flowers, Garscube Landscape Link (2010), Glasgow, UK. Source: Morris (2010). (b) entrance G (2012), Amsterdam, The Netherlands. Source: Carve (2012). (c) The Colourful Crossing (2016), London, UK. Source: Morby (2016). (d) Tom IV (2017), Montreal, Canada. Tom IV (2017)

Significant changes in colour design in traffic spaces are evident with the evolving role of urban spaces and other transformations in urbanism. In a globalised economy, countries and cities that heavily rely on the service industry, particularly tourism, must compete to attract investors and tourists (Madanipour, 2006). Urban spaces become crucial sites for building positive city images and showcasing vibrant urban life to attract global tourists. This research identified a notable increase in colourful temporary installations (N=53) in traffic spaces between 2014 and 2019 compared to the number between 2008 and 2013 (N=19). In these new projects aimed at reclaiming traffic spaces, employed not solely for the function of the physical space, saturated colours are also utilised to foster additional interaction with urban issues.

As shown in Figure 1.2c, eye-catching colours have been introduced to the pedestrian crossing to enhance road safety awareness. Beyond several blocks of bright colours, this crossing was created by Camille Walala, known for her distinctive colour palettes and Memphis style. Commissioned by the London Design Festival, this temporary design installation with vibrant colours aimed to portray the lively atmosphere of London City and announce the opening of the design festival. In this instance, saturated colours evoke associations with contemporary design, the trendy designer, and social events beyond this physical space. The dynamic meanings embedded in colours and the visually attractive ways of using colours help to attract broader audiences and promote the design along with related events. The growing popularity of using colours for branding in urban spaces can be attributed largely to the transformation in how we experience and interact with these spaces (Yu, 2023).

The prevalence of mobile phones brought about the success of social media worldwide. Individuals are keen to share attractive photos of themselves and where they have been online to demonstrate their attitudes and lifestyles to find like-minded people and approval (Manovich, 2016; Verwey, 2015). As social media platforms like Instagram and Facebook have become crucial gateways for envisioning and portraying cities, city authorities and other institutions have begun embracing and leveraging the power of colour. Figure 1.2d showcases one in a series of design installations commissioned by the Montreal Museum of Fine Arts and the City of Montreal that transformed a roadway into an exhibition (ccxa, 2017). Presented in imaginative and design-conscious forms reminiscent of fireworks, saturated colours evoke a festive ambiance while concurrently reclaiming traffic spaces for pedestrians to relish urban life. The amalgamation of saturated colours, design exhibitions, and vibrant urban scenery portrays an appealing cosmopolitan lifestyle, attracting visitors and encouraging them to capture and share photos. With the growing urban spaces involving saturated colours in lively urban scenes, such as the Pink Street in Lisbon, Portugal and Pigalle Basketball in Paris, France, vibrant hues become an identifier of dynamic urban lifestyles (see Figure 1.3a and Figure 1.3b).

Figure 1.3 - (a) Pink Street (2012), Lisbon, Portugal. Source: FG+SG Fotografia de Arquitectura (2012). (b) Pigalle Basketball 2020 (left); a model wearing Pigalle Branded Clothes(right) Source: Hypebeast (2020).

As saturated colour assumes a more significant role in branding urban spaces, defining the identity of cities, and depicting a cosmopolitan lifestyle, the design of saturated hues is poised to stay abreast of emerging trends in urban culture to remain competitive in the global market. Simultaneously, with the influence of social media, a place adorned with unique hues, such as the Paul Smith Pink Wall in Los Angeles and the Moroccan city of Chefchaouen, can swiftly become widely known and attract numerous visitors overnight (Kraus, 2022). Its capacity to capture attention and serve as a catalyst for change has been harnessed by businesses like Nike, with its colourful basketball courts spanning the globe, becoming a pivotal force in shaping the appearance of urban landscapes. With urban transformation, the links between saturated colours and social factors, as well as urban lifestyle branding, have strengthened. In this era of new urbanisms of colour, bright colours are likely to be imbued with multiple functions desired by society. The design of environmental colours, especially temporary colours, is inclined to be influenced by ongoing trends and demands in the urban environment compared to the era of "geography of colour."

Conclusions

This paper introduced and developed the concept of urbanisms of colour to investigate the radical changes in embracing saturated colours in urban and landscape designs. Urbanisms of colour provide a new lens to assess the changes in colour design by situating colour within the relevant urban context and exploring its diverse interrelations with urban issues. With the aid of this specialised lens, this paper focuses on the changes in colour design in traffic areas to illustrate how transformations in urbanism have led to changes in colour design and the growing trend of saturated colours. Through analysing relevant cases, this paper argues that we have entered an era of new urbanisms of colour where the intersection between colour and urbanism becomes more nuanced, reflecting not only the physical environment but also the cultural, social, and economic dimensions of urban life.

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Under the Skies of Gianluca Peluffo's Architecture. Color as Design and Landscape Strategy

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Abstract
Between 2015 and 2016 Gianluca Peluffo (Peluffo & Partners Architecture) realizes three architectural works where color is the key through which architecture fits into the landscape. These are three very different buildings in terms of size, program, form and materials. Peluffo's approach departs from those authorial color interpretations recognizable in terms of a coherent and systematic "language," such as the interventions of Sauerbruch - Hutton or Jorrit Tornquist. The elementary school in Zugliano in the province of Vicenza, - the first project analyzed - reconstructs through the inclined planes of its roof, the profile of the mountains on the horizon. A solution only apparently mimetic, which instead, places the work halfway between heaven and earth. Thus, the building declares its belonging to the context, but also reinforces its formal characteristics. The IULM extension in Milan, - the second project analyzed - in a suburb that is now almost a center, seems to want to dialogue with its surroundings through the use of materials typical of the built city. Then, suddenly, a red tower and an explosion of emerald green ceramics. Like a traffic light in the fog. In contrast, the headquarters of the BNL - BNP Paribas Real Estate group, - the latest project in this series - is located near the Tiburtina station. In an open, large, iridescent, luminous place, this building with mirrored surfaces is deformed, like a horizontal Brancusi, or a Boccioni painting, to gift and dynamically multiply of the sky of Rome. Gianluca Peluffo in these three projects has, on the one hand, the ability to construct three architectural figures based on color, on the other hand, he demonstrates a marked aptitude for descending into the context by developing on each occasion a different chromatic design strategy. Three inventions then, three ways of making the architectural work dialogue with the context, three exercises in specificity, in which the environmental, atmospheric dimension, identifies a type of "specific color." Three projects that dialogue with three different landscapes, the natural landscape of the Venetian foothills, the post-industrial urban landscape of Milan, and the infrastructured suburbs of Rome. Three landscapes, under three different skies, three atmospheres through which to decline the color of architecture.

Keywords: architecture, landscape, sky, Peluffo & Partners Architecture, architectural language

Introduction

Between 2015 and 2016 Gianluca Peluffo (Peluffo & Partners architecture) created three works where color is the key through which architecture fits into the landscape. These are three very different buildings in terms of size, program, form and materials. Three divergent projects, alternative to each other. It is in this aspect that this paper on the use of color in architecture is interested in exploring. Gianluca Peluffo's approach in fact departs from those authorial color interpretations recognizable in terms of a coherent and systematic "language", such as the interventions of Sauerbruch-Hutton or Jorrit Tornquist.

The elementary school in Zugliano (Femia and Peluffo, 2015) in the province of Vicenza, - the first project analyzed – reconstructs through the sloping planes of its roof the profile of the mountains on the horizon. The chromatic covering of the roof, in metal slats that vary in tones from gray to blue, is visible from the surrounding plain and the slopes of the Asiago plateau. A solution only apparently mimetic, which instead places the work halfway between heaven and earth. Thus the building declares its belonging to the place, but also reinforces its formal characteristics.

The IULM extension in Milan (Femia and Peluffo, 2015), - the second project studied – in a suburb that has almost become a center, seems to want to dialogue with its surroundings through the use of materials typical of the built city. Bricks, exposed concrete, glass, plaster, suddenly transfigured into a red tower and an explosion of emerald green ceramics. Like a traffic light in the fog, this project explores the signaling value of color.

In contrast, the headquarters for the BNL – BNP Paribas Real Estate group (Peluffo, 2016), - the last project in this series – is located near the Tiburtina station in Rome. An open place, with a sudden loss of density related to the railway infrastructure, where there are no presences of archeological or historic weight. In an open, large, iridescent, luminous place, this building with mirrored surfaces is deformed, like a horizontal Brancusi, or like a Boccioni painting, to give and enhance the dynamic multiplication of the sky of Rome through a color, or rather colors, that take on a metamorphic significance.

The heterogeneity of these three projects is intended to support the hypothesis that color can be used as a very versatile “material” that fuels creativity and through which it is possible to develop ever-changing design strategies that promote the specificity of the architectural work.

These strategies, understood as mediating solutions between architectural form and landscape, also allow the sky to be recognized as a structural chromatic element of the perceived landscape, and to give color a dimension at the “environmental” scale.

Finally, the reflection on these different strategies and the interpretation of the spirit of places through color allows for a reflection aimed at distinguishing between different and disjointed elements of architectural work, such as personal poetics, technique as transmissible knowledge, and authorial language.

School complex in Zugliano

“Building a school is a public event”, designing a building that is to welcome the future of the community is an important and symbolic occurrence.

In designing this new school complex in Zugliano, Peluffo imagines a school able to communicate with the territory and the landscape with an action that is both protective and protected.

The architectural Project (Prinsi, 2013) starts with the horizontal line of the building lot and the irregular profile of the surrounding mountains and hills. The building does not wish to disappear into the landscape but declares itself in its belonging to the context, highlighting and enhancing its natural features (Fig.1).

The school is fairly simple in its plan design, due to the specificities of the territory of the province of Vicenza, but also thanks to the morphology of the territory present in the lot and the absence of surrounding buildings. These premises have allowed for a geometric compositional simplicity of the plant made up of a square with a central courtyard, with the 15 classrooms, the offices, the canteen and a gym that open up around it. The simplicity of this geometry does not translate in section where the continuous roof is made up of roof pitches or sails, with all different inclinations to resemble the surrounding mountain peaks in order to create a formal connection with them, with the hills and with the Alps (Peluffo, 2015b).

The courtyard is characterized by the expressive nature of the light orange wood, used for the tree like pillars, also evocative of the context with their expressive formal image of branches that hold up large leaves, the pitches that project shadows onto the patio and enhance the feeling of intimacy of the closed space.

Fig. 1 – The Zugliano school complex. On the left: the building inserted in its context. Center: detail of the roof's cladding. Right: the inside view of the school's courtyard.

The sails facing the sky are made up of semi reflecting colored metal with different shades of blue to match and reflect the different colors of the sky during the day but also during the changing seasons. The initial idea for the roof was terracotta tiles, given the importance Peluffo associates with the ceramic workshop with which he makes most of the maquettes for his projects (Peluffo, 2023). The idea was discarded, however, due to budget problems, and the terracotta was replaced with metal (Fig. 1).

The role of the central courtyard is the heart of the school, understood as both the common and connective point. It represents the importance of experiencing freedom during the pause from the didactic activity. Along with the blue casing of the roof, the walls of the courtyard are painted in vibrant colors variating between red, orange, pink, and blue to achieve a fun and recognizable ambient for the children and the staff utilizing the space (Fig. 1).

In a short amount of time the school has given identity to the territory but also has become a reference point for the students and their families.

Iulm in Milano

The next project is the new IULM (*IULM_Milan / 5+1AAAlfonsoFemiaGianlucaPeluffo*, 2014) location, to be the main site of the Polytechnic school of Design and the IULM University Club. The headquarters are located in Milano Famagosta, a periphery that is slowly turning into a new center for the Italian city.

The new complex is made up of a building that within its 20.000 square meter lot constructs solids and voids with the same hierarchy. The building is organized throw a 9 stories tower and a 600 seats auditorium connected through the north and south wings along with a large multi-functional exhibition space (Peluffo, 2015a).

In a similar way to the Zugliano school, in plan the compositional layout seems elementary and simple, but in elevation it is possible to capture all the variations that create the rich and complex relationships with the intermediate spaces.

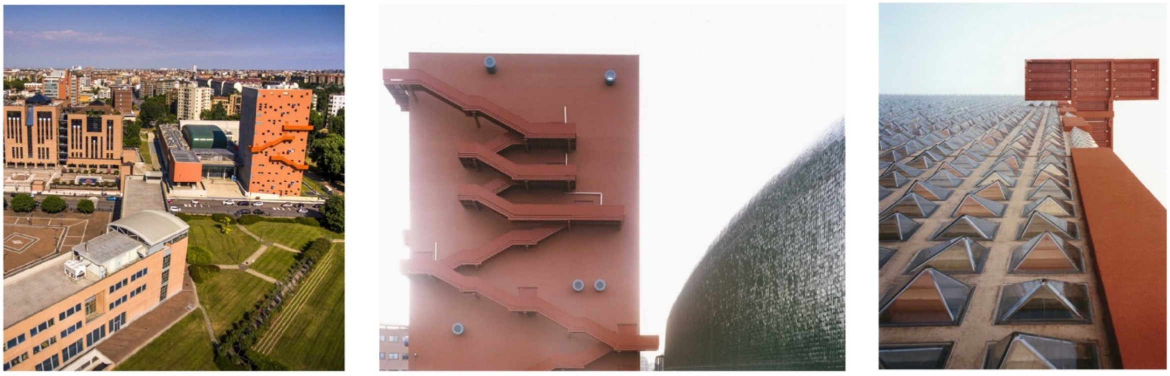

Fig. 2 – On the left: the IULM campus and the surrounding city. Center: the tower and the auditorium. Right: Detail of the dimond shaped glass inserts in the north façade of the tower.

The tower with the laboratories is the heart of the project, three of the facades facing the city are cladded in red-orange plaster and are lined with a continuous ramp of stairs that twists on its facades as an angular but unique promenade (Fig. 2). The metal of the promenade has been painted red to match the color of the plaster. This choice of material serves a double purpose, it is first of all an homage to the industrial past of this part of the city of Milano and the presence of the with its red-orange color of bricks, but most importantly its color wishes to become a sort of traffic light (Peluffo, 2023), always standing out against the often grey and foggy sky of the city. The third façade is lined with irregular pyramid shaped glass cement bricks (Fig. 2), reminiscent of the diamond-pointed bugnato in use in Italy in the second half of the 14th century. Because of the "pointed" glass the surface of the façade appears fairly opaque, but it lights up at night, or once again, in case of the typical gloomy climate of Milano. The tower in fact has been specifically cladded to suit the Milano weather, allowing the tower to both stand out and fit into the context.

At the center of the complex's solids and voids, almost embedded, is the 600-seat auditorium, cladded in green ceramic tiles (Fig.2), conveying disorientation and surprise. The building with its vibrant color represents an important junction of the complex that provides spaces not only for the university but also for the surrounding companies and the general neighborhood.

The complex as a hole is characterized by a clear emphasis on its volumes but especially on its chromatic aspects: the strong horizontality of the auditorium coexists with the verticality of the tower, just as the bright green of the auditorium building juxtaposes well with the warm brick tones of the plaster.

Bnl/Bnp Paribas Headquarters in Rome

The Bnl/Bnp Paribas building represents and signifies the spirit of the city of Rome and especially its sky. The sky of Rome and its light is one of its myths, and as such it belongs to everyone. The building is located near the Tiburtina station and the area is characterized by an unusual low density for Rome, mainly due to the presence of the railway infrastructure, whose presence is underscored

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by the railroad cistern by Angiolo Mazzoni, that has constrained (but also allowed) the building to break and deform around it.

The railroad then is representative of another myth, that of progress. In this sense one could say that the building finds itself in dialog with two myths: the Roman sky and the futurist and dynamic force of progres (Peluffo, 2023).

The building is inserted in a peculiar context, defined by the traces of the rails that were once separating two major urban areas, but has now achieved a central role in reuniting them. The lot is narrow and follows the longitudinal direction of the railway and for this reason, the two long facades face two very different urban situations, for this reason the building plays a defining role in its two-sided urban image (Peluffo, 2016).

The east façade of the building faces the Pietralata neighborhood, where the urban context is slow and still, and the continuous façade is flat and cladded with alternationg glass panels, reflective and transparent, and opaque diamond shaped ceramic tiles. This façade is characterized by the large black external staircase and the Mazzoni cistern, framed by a large breach of the building that also allows it to be seen from the west side.

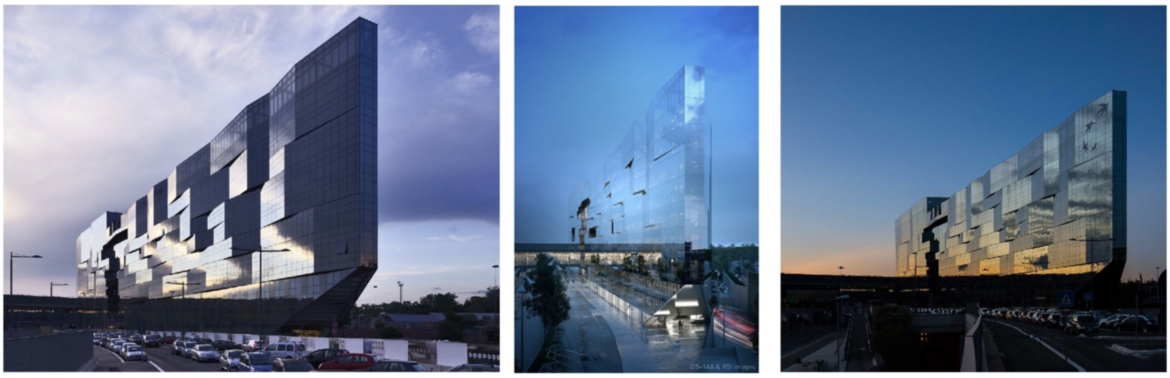

Fig. 3 – West façade of the Bnl/Bnp Paribas building at different times of the day.

The west façade (Fig.3), directly facing the railway and the train station, where the iridescent effect of the curtain wall materials is amplified by a regular sequence of indentations and protrusions, designed to be viewed from the coming and going fluxes of trains departing and arriving. Depending on the incident radius of the sunlight beams, the building absorbs, reflects, beams, and, after dark, it almost dissolves and blends in with the context.

Finally, in its southern part, the building become thin, it tapers into a bold cantilevered prow (Benetti, 2014).

It is possible to say then, that the Bnl/Bnp Paribas building dialogs with the context in a way that is not necessarily direct or explicit, but it is made up of perspective references with the urban landscape of Rome.

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Conclusions

Gianluca Peluffo in these three projects has, on the one hand, the ability to construct three architectural figures based on color, and on the other hand, he demonstrates a marked aptitude for immersing himself into the place by developing on each occasion a different chromatic design strategy.

The school in Zugliano uses the gray and blue tones of the sails of its roof, not so much to blend into the green plain at the foot of Asolo, but to build a dialogue, not only with the landscape at the local scale, but also at the territorial scale. Architecture through color dialogues with an enlarged landscape, with sweeping, panoramic views, where mountains stand out against a blurred sky, crossed by statuesque, solid, three-dimensional clouds like those of Mantegna (Peluffo, 2023).

IULM in Milan, on the other hand, through the timbral color of the red plaster of its tower and the green ceramic surface of the auditorium, dialogues with a diaphanous urban atmosphere. Milan's sky is made of fog, mist and hazy condensation, which do not hide the sunlight, but filter it by refraction. The result is a sky that has a volumetric, dusty texture, with a strong charge of abstraction and estrangement that recalls all paintings of Mario Sironi (Peluffo, 2023).

The Bnl Group headquarters, on the other hand, through its mirrored and oblique facades, recognizes an almost monumental value in the dimension of the Roman sky. The result is an architectural solution that is simultaneously immaterial and plastic. An architecture that feeds on the chromatic generosity and luminous richness of the skies of Rome like a futurist work by Tullio Crali (Peluffo, 2023).

Three interventions then, three ways of making the architectural work dialogue with the context, three exercises of specificity, in which the environmental, atmospheric dimension identifies a type of "specific color".

Three projects that dialogue with three different landscapes, the natural landscape of the Venetian foothills, the post-industrial urban landscape of Milan, and the infrastructure suburbs of Rome. Three landscapes but especially three different skies, three atmospheres through which to decline the color of architecture. Although the subject of different solutions, however, an interesting consideration emerges, the sky is always understood as an element of chromatic connotation of the landscape. In other words, the landscape no longer corresponds only to earthly elements, it is expanded. Through Gianluca Peluffo's projects, we understand that the landscape in order to be read and interpreted, must be observed along with its complementary element, the sky above it.

Moreover, in conclusion, once analyzed the projects and identified the strategies of landscape insertion, it is also possible to distinguish some aspects that concern design in general and that can be useful in reading and interpreting works of architecture, such as poetics, technique and language.

The first aspect starts from the assumption that design development involves an authorial issue. That is, there is a poetic dimension, of personal sensibility, which in the cases examined corresponds to the identification and choice of tone or agreement between architectural work and environment. In the cases presented, the "perceived surrounding", this "feeling of place", both in terms of suggestions and impressions, takes the form of an interpretation of the sky as a significant character of a place.

However, it is also possible to recognize a second methodological component related to the design technique. The relationship with the sky is established through the construction of precise and conscious chromatic relationships, from time to time established by analogy or contrast, by affinity or difference, nourished also through the dialogue with works of a pictorial character extracted from the repertoires of memory (the sculptural classicism of Andrea Mantegna, the metaphysical surrealism of Mario Sironi, the futurist aero-painting of Tullio Crali).

Fig. 3 – Left: Andrea Mantegna, ceiling of the *Camera degli sposi* (The room of the spouses). Center: Mario Sironi, *Paesaggio Urbano 1922-1923* (Urban Landscape). Right: Tullio Crali, detail of *Passione tra le nuvole* (Passion in the clowds).

Poetics and technique also have a bearing on architectural language, that is, on the communicative capacity of the forms brought into play by the author. In particular, the architectural intention in the projects presented is not formalized and exhausted only in the plastic terms of the composition of three-dimensional figures. The figures that emerge from the projects studied, these ordered systems of signs, acquire meaning, become appropriate and specific with respect to a place and a moment, thanks to the use of color.

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7. Color and Design

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Serlumen - Conscious Action Beyond the Anthropocene

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Abstract

The author presents us in this paper the main results of his Design Doctorate (PhD) scientific research , and his research team. This research have as central object of study "**The Natural Pigments of Serras do Socorro and Archeira and Their Usage by Live With Earth Association**" and started in 2019, funded by FCT – Fundação Para a Ciência e Tecnologia. During this 4th year of research, some groundbreaking results are being achieved, in a balance between theory and practice innovations, with focus on applied research. In terms of knowledge, it was invented a new theory, that at first, brings new questions and hypothesis for static and dynamic colors, in the paper " **Visual and Sensory Perceptions Between Static and Dynamic Colors** " presented in ***AIC 2021 , 14th Congress Milan***. At a second moment, following the study and development of this new hypothesis, it was created an iconic and pioneer paper that presents "**A New Paradigm for the Definition and Universe of Static Colors and Dynamic Colors**", presented in the ***XVII Color Conference, Florence 2022.*** Meanwhile, and following the studies of the Design Phd Research, these scientific papers transformed in a new vision, not only for the definition and meaning of static colors and dynamic colors, but through this discoveries, for a new "**Mindset for Conscious Action Outside of the Anthropocene**" called "**Serlumen**", revealed in this new paper, for presenting in the ***XVIII Color Conference, Lecco 2023.***

Serlumen means "ob**SER**vador (Mente) + **LU**z (Cor) + pig**MEN**to (Sociedade)", and merges together the three concepts of the triangulations resulting from the divergence-convergence design research methodology. Is a new mindset, which investigates within the areas of Design Thinking, Circular Design and Design for Social Innovation, with a transdisciplinar approach, crossing several sciences in a map that gives them a direction and a common purpose. This purpose, in it's higher level, is to **align the "human intelligence" with "Gaia's intelligence"**, in order to raise and develop the **"Conscious Action"**. It presents us a new framework for designers and for usage any other discipline or science that is willing to design a new society, based in the **5 Dimensions (D's)**: **Direction; Democracy; Degrowth; Decentralization and Decarbonization**, and in it's mindmaps nammed as **"Serlumen Constelations"**: **1) From Micro to Macro; 2) From Self to Wholeness and 3) From Local, to Global, to Universal.** Serlumen proposes, in practice, a new "**Social Innovation Model: Design Research Cycles & Live With Earth DC4SD – Design Conference for Sustainable Development"**, to apply it's vision in a real context. This context is the village of Cadriceira, through Live With Earth Organization, and integrated in the ECO CAMPUS – Torres Vedras, an enterprise group for Green Economy born from the awarded recognition of this city with the European Green Leaf 2015 award , in a model of local action for global change, from Portugal to the world.

Keywords: natural pigments, design thinking, social innovation, serlumen, static colors and dynamic colors

A New Paradigm for the Definition and Universe of Static Colors and Dynamic Colors

Colors are in permanent communication. There is a big difference between the colors of a village and the colors of a forest. I call this difference static (or humanized) colors and dynamic (or natural) colors.

An isolated, single-color pigment composed of thousands of similar powder grains represents the order of group. Whereas, when we introduce another isolated pigment, they become two pigments that generate the order of symmetry, from the micro to the macro. Joining a yellow pigment with a red pigment, they never merge, but mixing at the microscale, in the perception of the human eye appears an orange color. It is in this way that we bring to the universe of colors, the universal laws, from the micro to the macro, between orders of group and orders of symmetry, in expansion and contraction, in divergence and convergence.

Static colors are usually produced and/or cataloged by humans. They may or may not vary over time, light, and erosion. These colors is as if they were the "music of colors", where in similarity to the 7 musical notes, which were created from an almost infinite number of sounds of nature, also 7 colors of the rainbow were observed, analyzed and cataloged as the main colors, within the electromagnetic spectrum, in visible light, and which are the summary of an almost infinite amount of different colors existing in nature. This is the result of the fact that the human being has used a mathematical, rational and organizational thinking, to categorize the colors, and in this way in my view, making them static, within his own world, or group, existing in the symmetry of the universe. It is as if it were the creation of a language or a code, which makes them more perceptible among humans, easy to read, understand and communicate. *Static colors* come mostly from inorganic or non-living sources, and communicate the processes and phenomena that happen mainly in human nature.

Dynamic colors are the source, and the basis of *static colors*, and they are the colors that exist by themselves, and that change mostly in short periods of time, but that can also change in long periods of time. They always vary with time, light and erosion. Much of the *dynamic colors* come from natural sources, and communicate the processes and phenomena that happen in nature, including humans as part of it. Examples of these processes and phenomena are the depths, dimensions, opacities, densities, levels of toxicity, whether a food is edible or not, states of maturation of food, states of decomposition of objects, the existence of infections or bacteriological processes, if there is the presence or processes related to fungi, in the leaves of plants are reported different aspects, stains, colors, patterns, which communicate to us various information about their health and balance, potentially poisonous animals, among other innumerable information that is communicated to us through the colors of nature. This is the main, the most basic, primary and primitive form of the existence of a communication between nature and the human being, of the existence of communication of nature to itself, deep down, and also integrating the human being, for the human is also nature. We can understand with our gaze and with the process of vision, the world in front of us, without any other language, for this is the first language: that which colors transmit to us, and the information that colors provide us, about the world, but also about ourselves and about our interpretation of the world.

Serlumen: Conscious Action Beyond The Anthropocene

Serlumen expresses the search for Universal Consciousness beyond the Anthropocene. It is a model that operates from the micro to the macro, from the self to the whole, from the local to global to universal. It is to be part of nature as a whole. Integrate as a human being, part of nature, and creator of it, according to all other existing elements. Living and non-living beings. Visible and invisible entities. Stable and unstable memories. Serlumen is to see beyond the Anthropocene, the human egocentric sphere. This sphere has been the focus of growing influence of human beings, from the individual to the collective, the social and the global. Humanity thinking that it is the center of the Universe, or even that it is thinking of itself as the center of Gaia, is unthinkable, intolerable, illusory... Serlumen is to leave this sphere of the Anthropocene, the set of thoughts of the static mind developed from excessive patriarchy and chapters of recent history, which have caused humanity to cross the line that integrated it within nature. Since then, one has been thinking and seeing oneself outside this line, and in illusory control of nature, of which one forgets that one is a part. Anthropocene is the creation of a human nature that imposes itself on natural, and universal nature, and that we can observe mainly in "developed" countries. Serlumen is therefore a step of evolution. A new way of thinking, of seeing, of observing, everything that can be questioned. It means “obSERvador” (observer), “LUz” (light) and “pigMENto” (pigment), in the same word. The origin of the word refers to: The observer, derived from the studies of the mind; the light, derived from color studies; and pigment, derived from society studies. It is a theory that results from the advanced methodology in transdisciplinary design, of divergence-convergence. Each of these concepts, representing the variables of the theory, are always in association with the permanent resolution of the static-dynamic relationship.

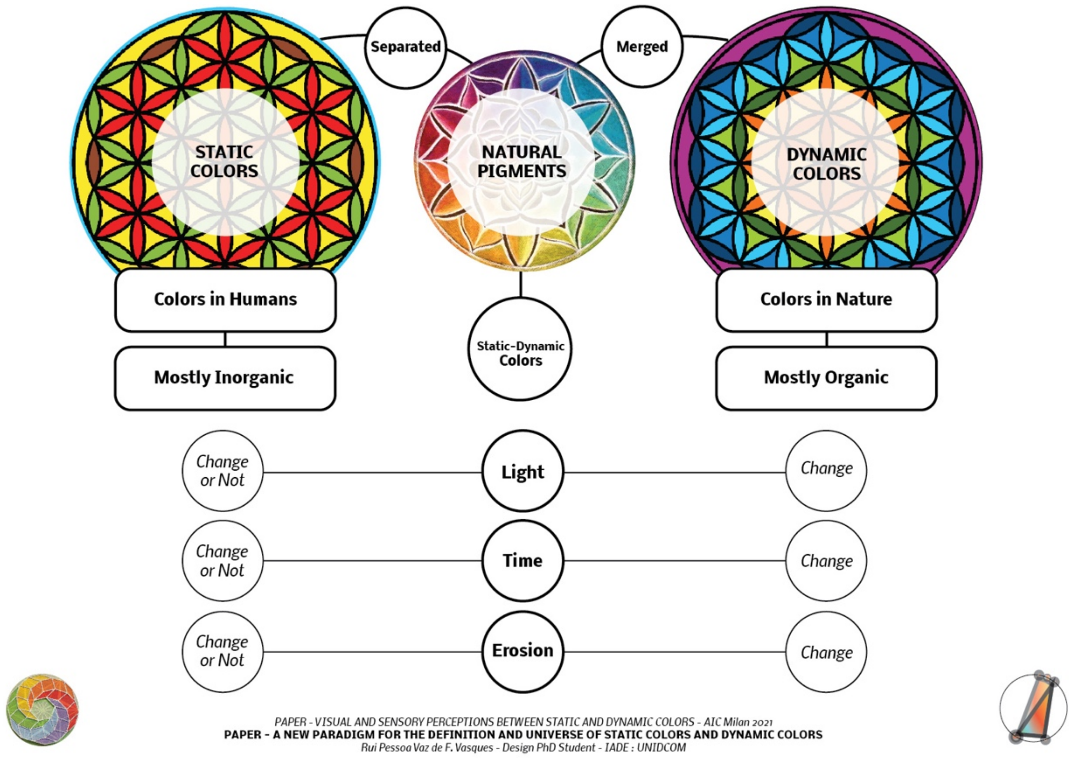

Fig. 1 - A new paradigm for the definition and universe of static colors and dynamic colors

Serlumen is concerned with some central issues, and propose new insights for the questions: **What is Light? What is color? What is static and what is dynamic? What are the current definitions of static colors and dynamic colors?** In common sense, static colors are the cold colors, associated with the earth poles and dynamic colors are the warm colors, associated with the equator. This is the current definition, which we consider quite reductive and far from the potential of a holistic definition, which brings us greater understanding and potential for discovery about colors, and specially a definition that can serve humanity and general evolution nowadays. That is why we present a new paradigm for *static colors* and *dynamic colors*, which argues that *static colors* are a result of the human being and *dynamic colors* are a result of nature. *Static colors* as the group order (static), the human being, developed within the ideas of human creation, and *dynamic colors* as the order of symmetry (dynamic) source of all colors, the colors of nature in permanent mutation and transformation. Serlumen, argues that natural pigments are one of the bridges between *static colors* and *dynamic colors*, which make the transition between the colors fused in nature to the colors separated and categorized by humans.

Serlumen is a new mindset, which investigates within the area of Design, namely Circular Design and Design for Social Innovation, in a transdisciplinary way, crossing several sciences in a map that gives them a context, a direction and a common purpose. This theory officially emerged in the publication of the article "VISUAL AND SENSORY PERCEPTIONS BETWEEN STATIC AND DYNAMIC COLORS, Vasques R., Abreu D., Rodrigues A.", which took place at the AIC 14th Congress Milano 2021, and which was widely accepted and praised by the scientific community. For the first time, the current concept and definition of "Static Colors and Dynamic Colors" was questioned and a new way of looking at these concepts, as well as colors in general, and light, in different forms of human thought and perception, was presented. These concepts evolved into a second article, which presents for the first time Serlumen's theory, officially in the publication of the article "A New Paradigm for the Definition and Universe of Static Colors and Dynamic Colors, Vasques R., Abreu D., Rodrigues A.", which took place at the XVII CdC Conferenza del Colore in Florence 2022.

The 5 Dimensions (D's) of Serlumen

The **5 dimensions of Serlumen** appeared in a beautiful old waterfalls in Tábua (Portugal), where we could observe and feel how people lived in the past, by using water to turn the hydraulic mills and provide the conditions for the tasks linked to the survival and evolution of local communities, based on the strength and energy of nature. That's when the idea of the 5 Dimensions came up, which happen as follows.

First is the **Direction**, which means to show the way. It means leadership, and that there is a definite direction, a common vision for a locality, especially in rural areas, because so many localities are abandoned and in this way they have lost or are losing their identity and with them their direction. Often this first dimension is attempted through the parish councils, but we know that these often do not serve the populations as much as they should, ending up not being able to hold this vision and this direction, by identifying the real valences and means of uniting people, reinforcing identity and leading the direction. With a wider range of growth, social cohesion and long-term. The second dimension is **Democracy**. If there is a direction, we can create mechanisms of interaction and participatory mechanisms. When there are these ways of acting, which we describe in the first dimension, we are enhancing democracy, because people, of their own free will, can participate or not in this direction, can suggest changes or ramifications of the direction, can suggest new ways of doing, additions, etc. If there is a direction and it is clear to everyone, then there can be room for people to contribute to that direction. Here democracy is generated, as also active participation, dialogue with the community, collective dynamics and interactions, social strengthening and cohesion. Opening ways for people to give their opinions, their contributions, and also using ethnographic studies and social impact meters, so that we can listen to populations and understand at levels of greater depth each of the people and what they have in common, as well as their differences, and other variables. We can then, after this work, improve the mechanisms that guarantee democracy, participation and common evolution. Making leadership transparent, and inclusive for all. When we act in this way, we are creating strong and resilient systems, and this aspect must begin in education. Education systems should not teach children by putting them all in the same place as equal or similar. We're all human beings, but we're all so different, and we bring such different potentials. Education has to know how to look at and understand these differences, to be able to integrate these different potentials in the best way, and channel each learning process, of each child, taking it to the maximum of the potential of each one in their growth, in their lives, in social life and also in collective life. The third dimension is **Degrowth**. Degrowth is a growing global movement involving thousands of scientists and thinkers, in all areas and around the world. It is an interdisciplinary and transdisciplinary movement that advocates the deceleration of planetary civilization. Looking at exaggerated and uncontrolled capitalism, in an illusory infinite growth, looking at all the catastrophes we face today, from environmental catastrophes, to human and economic catastrophes, we realize that capitalism is not the solution, but rather the central problem (D'Alisa et al., 2016). Mainly at the level of the population, and consequent survival mechanisms, social mechanisms that make this population exist and manage to survive and grow. Looking at how the population is related to society and the size of society, and the capacity that it has to sustain this population and that comes from the basis of survival: food, health, energy, infrastructure, education and other social sectors. After degrowth comes the dimension of **Decentralization**. We observe today a society, and a planetary civilization, that has evolved in this unbridled capitalism and through centralized structures. The economy has its centralization points, such as world banks, national banks, large financial groups, etc. Health has its centralized groups, such as the large pharmaceutical industries, large health groups, which control the medicines, chemicals, technologies and machines that are available to conventional hospitals... The great structures of education, which shape the current education to a style of the current society, that is, to the lifestyle that it produces, especially in the so-called "modern" societies... Mainly, at the level of power. The powers installed at the global level, the power of politics, the power of large corporations, which use and abuse, exploiting the vast majority of resources in an inordinate and irresponsible way. Military power, oppression, and manipulating people through fear, weapons, violence and wars. The power of the mass media, which often invent the speeches, even though we know that there is good and bad journalism. The media have great power over populations, over the mentalities of populations and in this way, also over population control. The power of a few companies that dominate virtually all existing market sectors, industrial and commercial, such as the industries and power structures of oil and fossil fuel derivatives, which have to disappear or change radically and quickly, giving wings to other sources of energy and natural materials to replace materials from oil. Is urgent to decentralize most of these structures.

Fig. 2 - The 5 Dimensions (d's) of serlumen

All of this brings us to the fifth dimension, **Decarbonization**. When there is a direction, when that direction becomes a democracy, when that democracy and that direction are aligned with degrowth, when degrowth is acting in processes of decentralization, decarbonization will happen naturally. All targets to reduce carbon from the atmosphere, and targets to reduce carbon emissions, will at that time drastically become more efficient and quickly achieve their goals. Carbon emissions will gradually disappear during the application of this process, from dimension 1 to dimension 5, and especially in dimension 5, where all the conditions will be met for the success curve to become exponentially positive. Decarbonization will happen with a considerable greater impact, when we act in the macro sphere, of large businesses, companies and industries that emit huge amounts of carbon and other polluting gases, and when the main sources of energy become ecologic. What we seek with these models of thought and action is above all to provide open access to knowledge, so that individuals and collectives can apply it in their daily lives, in their visions, missions, projects and actions.

Serlumen Constelation : From Micro to Macro

The Serlumen constelation “from micro to macro” has a strong influence on the book "Everything Forever" by Gevin Giorbran (2007), highlighting the chapter that reveals the studies on the order of group and the order of symmetry. It is a dualism existing in the universe, and consequently, at different scales from the micro to the macro, in this endless cycle, as systems of fractals that change scale and at the same time continue with the same configuration of patterns, varying in forms and functions. This is how they work, explaining in a simple way, the order of group and the order of symmetry, both in isolation and together and in different patterns where they merge, and configurations that they generate. In this sense it is interesting to understand that for Serlumen, in the study of *static colors* and *dynamic colors*, and in the proposal of a new theory for these concepts, in the micro and order of group we observe humanity, and in the macro and order of symmetry the whole, nature or the universe.

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Starting from the new concepts on the realm of color, supported by the concepts of mind and society realms, the constelations of Serlumen are one of it's higher expressions, as theoretical and practical tools for knowledge and action. Beside many other questions that arises when we create and develop this constelations, we highlight: **From the intelligence of human beings to the intelligence of Gaia (nature), what are their characteristics, ways of functioning, what are their relationships, and how can we amplify the potential of these relationships, in synergy and in an evolutionary matrix?**

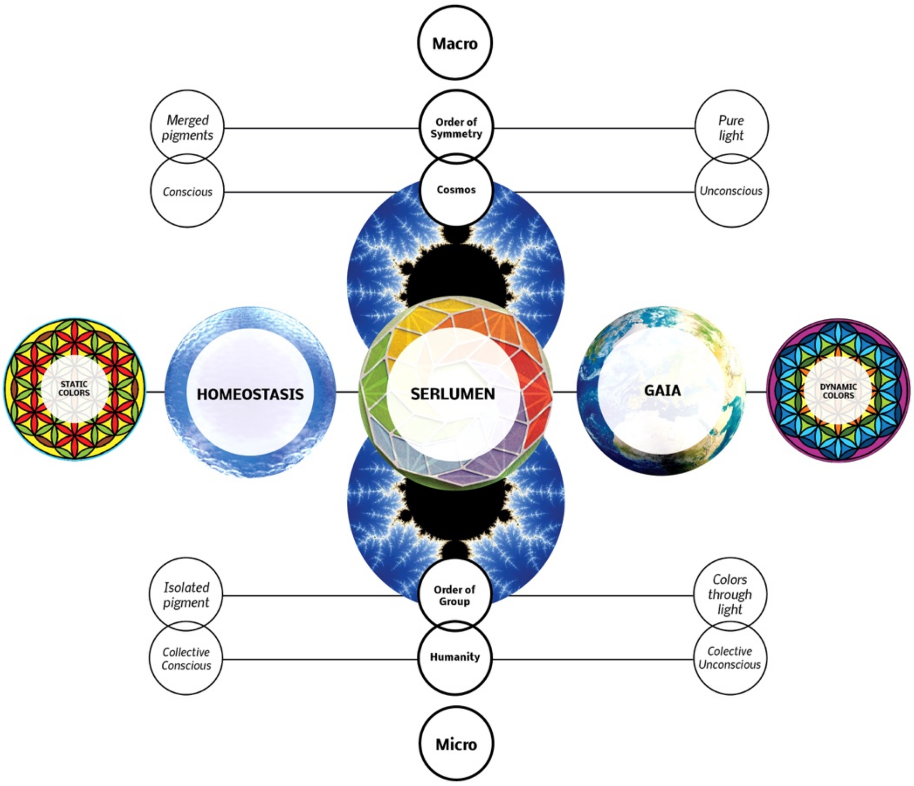

Fig. 3 – Serlumen constelation : From micro to macro

Serlumen Constelation : From Self to Wholeness

From Self to Wholeness presents a perspective that is based on a foundation of human development, and of human positioning outside the Anthropocene. It explains the same theory, but through another prism, another lens. From a holistic look or perspective, complementary to the other constellations presented in the theory. Starting from the Self, this Self being a order of group, and the Whole being the order of symmetry, at the level of the Self and the group, we have two pillars, of creation and of manifestation. Creation departing toward the Whole, upper/heaven, and manifestation departing toward the lower/earth Self, at the level of materialization. These strands of creation and manifestation happen at two levels: at the static level, of the designer, and of the communication made through the designer, of *static colors*, and at the level of dynamics, and of *dynamic colors*, such as communication made through life, communication of the colors of nature, in the phenomena of life. This system should generate a greater perception of what Serlumen is, of what the new theory of *static colors* and *dynamic colors* is, and of its existence at the level of hierarchy, of positioning, and from the micro to the macro scale, and how these two intelligences work in parallel, from human intelligence, to Gaia's intelligence.

How are these intelligences related to consciousness and the unconscious? How are they related to homeostasis and Gaia? And by itself, how do the colors manifest themselves in this parallelism and in each of these polarities, and at each level of these scales of polarities, frequency, dimension, but also temporal, in another observation, and opening doors for other investigations that may arise through Serlumen?

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Through this perspective, we can observe the sphere of the human being, the sphere of the Anthropocene, the sphere of the use of colors by the human being, and we can compare and relate these spheres, with the sphere of nature and the universe, and the sphere of colors in nature, and the way nature itself uses colors to communicate, It uses colors as mechanisms for balance and evolution.

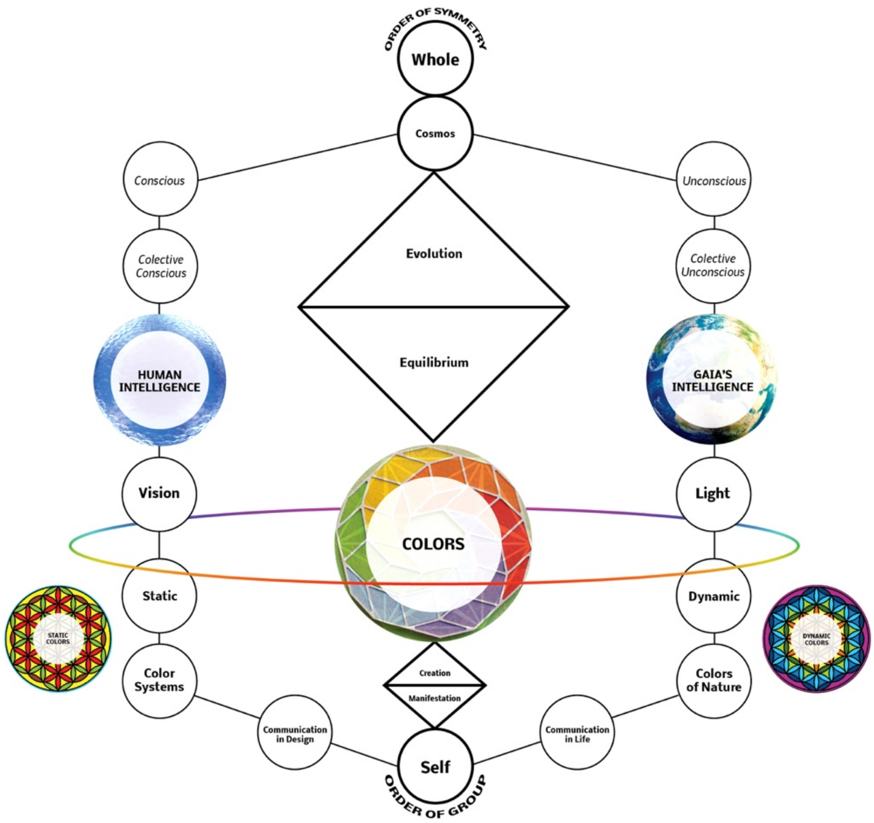

Fig. 4 – Serlumen Constelation : From Self to Wholeness

How can we individuals understand this? And how can we designers communicate through colors, understanding all these concepts and these relationships, understanding Serlumen in its depth and in its multiplicities, transversalities and transdisciplinarities? Being better designers, communicating better, using *static colors* for processes of creation and manifestation, which are aligned with the communication of life and nature, above all. May they be aligned with the greater purposes of life and existence. This is one of Serlumen's great messages: when we align the Self with the Wholeness, as designers, or as any other profession/activity of everyday life, especially those who work in the field of colors, study colors or use colors regularly. But also for any profession or person, who can understand these concepts through colors, communication and vision. Reinforcing the question of purpose, present essentially at the level of homeostasis and Gaia, in which the survival, balance and evolution of the human being, must be linked, in synergy and cooperation with that which is Mother Earth, our common home, and the manager of all life.

Serlumen Constelation : From Local, To Global, To Universal

Design focused on meeting basic human needs within local communities or regions creates important redundancies, safeguarding against unforeseen disruptions in one area from causing widespread consequences. In contrast to the neoclassical economic pursuit of efficiency at all costs, which can harm the broader system, redundancy is essential for thriving local economies and regional resilience when striving to build circular economies based on local, renewable resources, with innovative solutions rooted in the unique characteristics of each place and culture. (Wahl, 2016, p. 76) While the first constellation communicates to us in a scenario and in a language of physics and quantum physics, the second constellation communicates in a scenario and in a language of design, spirituality and individual action, the third constellation communicates in a scenario and in a language of collective action and society. This figure presents us with a perspective of action, with the intention of guiding human beings to collective conscious action, which acts in respect and alignment with their own individuals, with the way they interact with other individuals and collectivities, and with the respect and protection of natural resources, in an efficient and regenerative way of using them.It is important to understand that Serlumen is a way of thinking, an awareness, a mindset, which places us beyond the Anthropocene, and side by side, in cooperation and synergy with nature. Hence we realize that in the Local work together the natural resources and the human resources, that in the Global work together the homeostasis, in functions of the human intelligence, and the intelligence of Gaia, and that in the Universal work together the Conscious and the Unconscious, in permanent decision-making and action, by the Conscious Action.

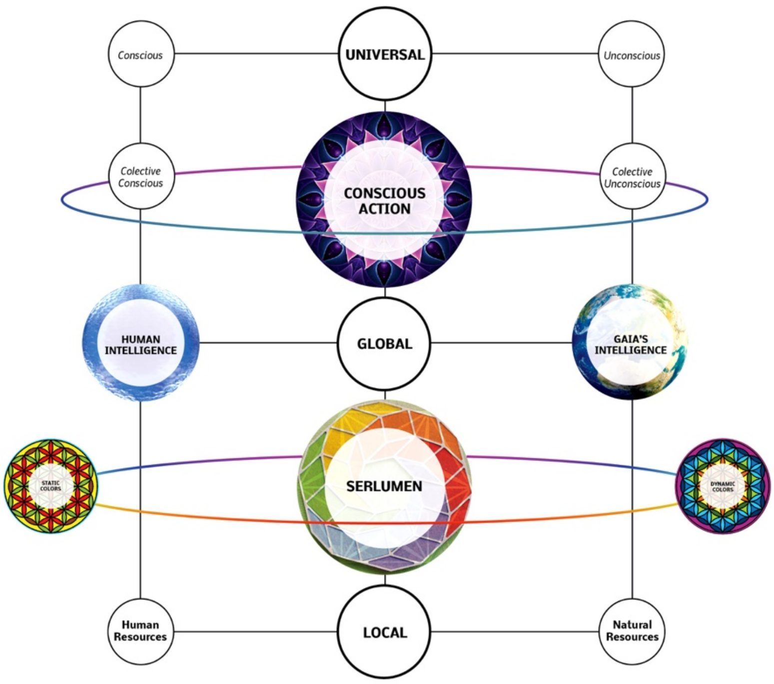

Fig. 5 – Serlumen Constelation : From Local to Global To Universal

Conclusions

Beside what we present in this article, the theory and vision of Serlumen is transversal to any science, domain, area or discipline, as it represents a mindset, lifestyle and way of being. In the author's thesis it is described how this vision can be applied and developed in other domains such as: Education, Social Entrepreneurship, Eco-Design, Eco-Arts, Eco-Construction, Energy, Economy, Ecology, Technology, Conscious Unconscious and Subconscious, Culture, Spirituality and Religion, Space, Time, Science, Scientific Research, and others. This shows us that is possible to redesign society in all it's structures, starting from the ways of thinking, to the ways of acting, to the ways of behaving, bringing new sustainable and regenerative solutions which brings us hope and wisdom for the future of humanity on Earth.

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Vasques, R., & , Rodrigues, A. C. , Abreu, D. (2022, 12-13 Sep). A New Paradigm for the Definition and Universe of Static Colors and Dynamic Colors, [Paper and Presentation] in XVII COLOR CONFERENCE, Florence, Italy, Gruppo Del Colore, Associazione Italiana Colore, https://www.gruppodelcolore.org , ISBN 978-88-99513-18-4 DOI: 10.23738/RCASB.006 , Universidade Europeia, IADE, Faculdade de Design, Tecnologia e Comunicação, UNIDCOM/IADE, Unidade de Investigação em Design e Comunicação, Av. D. Carlos I, 4, 1200-649 Lisboa, Portugal, Este trabalho é financiado por fundos nacionais através da FCT –Fundação para a Ciência e a Tecnologia

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Design of personalized fragrance platform based on color perception

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Abstract

The increasing demand for beauty products across the globe is accelerating the beauty industry. According to the network service for personalized fragrance, there are currently many online platforms which propose a shopping experience based on some personalized key elements. Color is one of the most important factors for the decisions regarding product choice such as perfume. Odors don't have any visual elements, so people usually synthesize them with different colors, patterns, and shapes. For color-odor association and colorimetry, both perceptual and semantic factors seem to play a role. The congruency of color-odor pairs is reflected in the activity of brain areas associated with the hedonics of smell. In conclusion, color influences odor identification, discrimination, intensity, and even pleasantness. This paper primarily focuses on developing a personalized perfume platform of Iranian fragrances, as well as conducting system requirements analysis, database design, functional module design, implementation, and testing on this foundation. Facing the potentiality of the visual stimuli in optimizing the user experience at the moment of choosing and buying on a virtual platform, the contribution of odors' colors with a "unit of selective elements" is at the center of this research. The purpose of this paper is to develop a specific platform, which would allow the fabrication process of the personalized perfume evoked by colors in terms of olfactory experience by users. The use of verbal metaphor is discussed to describe fragrances, and also to know about the possibility of associating odors and colors through such metaphors and how colors affect individuals' attitude and purchase intention in the context of online platform. Using the appropriate colors in an online platform can enhance the communication, and the perception of the quality of a perfume can be anticipated even before it is smelt. The IDEO method is selected as the creative process of this study with different research and creation tools which allow data gathering and idea generation. This research work contributes to shed some light into color perception and e-commerce strategy thus helping marketers and designers to create more effective online platforms.

Keywords: color perception, color-odor association, fragrance, online platform design, personalization.

Introduction

We are surrounded with variety of colors and odors which bring us different messages. Online shopping gives an unlimited access to the physical and non physical products and services all around the world in a multitude of ways. 'Uroma' provids people the opportunity to discover the traditional and authentic perfumes and personalise them. It will be beneficial for the different aspects of economical growth of each locality and also emotional response to the need of the amators of fragrances. Perfume customers are interested in the properties of their perfume and their composition. As well as a lot of different sale concepts in marketing, perfume preparing can also be taught to a public who are already interested in such product. The color-odor association is a good and fun manner to learn this basicly chimique science. Including people's favorite colors in their perfume selection help them learn this concept in a playful manner. This paper presents a new approach for involving people in the whole process of preparing a perfume based on their favorite composition via the color codes and an interactive online plateform. This concept uses different colors to inform people about perfume composition, quality, quantity and also different effects that can be produced after using it. In order to choose the favorite color palette, based on IDEO method, the card sorting tool was used to understand the general level of the olfactory cycle by users. In this way, four main families of the olfactory cycle (oriental, floral, fresh, woody) are placed in the form of columns to classify the randomly arranged cards. On each card there is one of the scent notes along with its picture (to help recall the scents). Also, for this purpose, *provenbyusers.com* online platform was used. The results of using this tool were analyzed in two ways. One is the level of agreement of the participants in the scents of each family and the other is their actual familiarity with the cycle of scents based on correct answers. In order to get to know more about the user group and obtaining more information about how they use and know about scents and the smell cycle, a deep interview was conducted with a group of 10 individuals (8 perfume amators and 2 perfume sellers). The outcome of these interviews was used in a design to improve the interaction of users on online platform and to create new forms of sensory process of buying a personalised fragrance. This research aims to find a solution for involving individuals in the whole process of choosing and buying a spcific perfum by including different colores.

Color-odor association in the context of online shopping strategy

Comunicating about the smell experience through words is difficult for people (Engen, 1982). This difficulty limits the usefuleness of verbal communication in fragrance marketing. Several studies show the consistent relationships between percieved odor properties and color properties. One of the first systematic studies on the topic shows that color matches for various equi-intense fragrance materials differed on the saturation and brightness (Gilbert, Martin and Kemp, 1996). Another study results that matching colors generally has greater variation in hue across than within odors, while percieved intensity was related to brightness (Kemp and Gilbert, 1997). In another study an odor-color matching research is performed in which the comlex fine fragrances and color chips from the NCS color system as stimuli is used (Schifferstein and Tanudjaja, 2004). In a recent study, it is mentioned that color dimensions can be related to the different types of fragrances families (Kim, 2013). An overview on all of these studies shows that there are some relations betwen odor perception dimensions (intensity, odor quality) and color perception dimensions (hue, saturation, brightness). The odor-color associations existe in self-report studies, but also in imlicit association tasks for a number of specific odor-color pairs (Dematte *et al.*, 2006).

Choosing a perfume is not a chance; several theories existe about the physical and psychological factors that influence the choice of a particular fragrance. One view holds that perfume choice is irrational and cannot be explained in psychological terms. Another group represents the view that external characteristics, such as the color of a person’s hair or eyes, determine the choice of perfume (Jellinek, 1951). The last and most important point of view focuses on the relationship between a person’s personality and his/her choice of perfumes; It seems that this approach is continuously expanding (Corbin, 1986). The connection between personality and perfume was initially a hypothesis, but the latest research in the field of psycho-physiology confirms this idea (Müller, 1984). Scents are usually immediately categorized as pleasant or not (Chebat and Michon, 2003). Despite the cultural drivers of scent preferences, odor pleasantness is a relatively personal matter; Because it is related to the past personal experiences. A smell that is negative or in other words unpleasant is often general (Wilkie, 1995).

Businesses seek to explore the opportunities of the awareness of the power of scent to influence the brand experience. Martin Lindstrom found that brand impact increases by 30% when more than one sense is involved and 70% when three senses are integrated into the brand message. Smells have an immediate and compelling effect because they directly connect to the limbic system of the brain, which is the responsible part of the brain for our memories and emotions; Therefore, scents are beyond our rational perception and have a final effect on our emotions (Lindstrom, 2006). Researchers hypothesize that the degree of the complexity of a fragrance may affect the consumer's ability to process olfactory information. The less complex a scent is, the easier it is to process and the greater its impact on related attitudes and behaviors (Iles, 2017). *Sensory marketing* is a branch of marketing that seeks to use the five senses in order to influence the minds of customers. In this type of marketing, by stimulating each of the senses or combinations of senses, it is tried to change the environmental and perceptible conditions in a favorable way, and through that, to encourage the customer. This persuasion generally creates a pleasant feeling of presence in the space and by combining sensory-cognitive factors in order to create a meaningful connection between the brand and the presented sensory components in the customer's mind (Bertil, 2011). It is important to know that 75% of our emotions can be activated by scent (Martin, 2005). It should even be considered that the scent can play a moderating role when people are expected to have an unfavorable or good feeling towards a subject (Ellen and Bone, 1998).

Color influence on decision making and perfume personnalisation

The psychological appeal of scents has long been an important tool in the perfumery industry. In fact, in the modern era, perfume has turned from a luxury product that was reserved for a few people into a daily consumer product. In fact, the market is flooded with all kinds of perfumes (today there are more than 800 perfume lines); Therefore, the customer inevitably faces problems in choosing a perfume. Perfume is a more intangible and even more confusing product for consumers. Even if we were to list all the ingredients on a bottle, it wouldn't help the consumer much, because we're dealing with a world of perceptions, emotions, and aesthetics. Everything presented to the user - the shape and color of the packaging, the design and form of the bottle and the precious contents - are the symbols. The main role of the perfumer is to decipher these symbols and make them understandable. Research results show that a fragrance that is captivating has an effect through three areas: mental experience, lifestyle and social/biological data/climatic factors. Companies don't just sell a simple perfume, but offer a complete ingredient that includes an experience that awakens one's emotions when using the perfume; Therefore, it is necessary that in a commercial advertising, we touch the intangible aspects of the product, shapes and images accompany the process of expression (Consoli, 2010).

So adding emotional appeals to a product will help its consideration by people. Emotions always play a role in every purchase, and even in many purchases, the role of emotions is much stronger than reason and logic. Emotions act as a catalyst in the engine of the purchase decision process. Customers often attribute rational and logical reasons to their purchases and try to prove that they made a logical purchase and that emotions did not play a role in their decision; But the ultimate driver is emotion, which plays a major role in the final purchase decision. Rather than being attracted to product features, customers want to know whether the product matches their personality. Therefore, companies that want to stand at the top of the competition should use emotional marketing as their competitive strategy to have as much market share as possible (Joshi, 2010).

Olfactory experience and hedonics of smell

It was imagined that the sense of smell does not play a very important role in human life; But currently, studies show that several areas of the brain, including the amygdala, insular cortex, and cerebellum, are activated when exposed to an olfactory stimulus (Freeman *et al.*, 2009). A study conducted by Rockefeller University in New York showed that a persons remember 35% of what they smell, while only 5% of what they see, 2% of what they hear and 1% of what they touch (Rockefeller Edu, 1999). The ability of scents to evoke the deepest feelings and recall memories is very high. Over the course of a person's life, the olfactory system changes and adds new scents in response to different experiences to build a complex *"olfactory bank"* associated with memories and emotions. According to the model shown in Fig. 1, it can be seen that the most effective events are those that bypass the connections of the conscious mind. This is exactly what perfume does, targeting the *"inner mind"* directly. The findings suggest that unpleasant odors act as warning signals and help humans stay alert to potential threats in the environment. Also, evidence of the cognitive function of the olfactory system is effective in supporting arguments related to evolutionary psychology and everyday life situations in the real world (Van Toller and Dodd, 2012). In a seminar, Wilkie stated that among the five senses, smell is the closest sense to the emotional response of the brain. By bringing physiological and scientific evidence, he showed that the human perception of smell along with the interpretation of the environment is a mixture that can determine a significant part of a person's behavior when he/she contact with the environment at the moment (Wilkie, 1995). The limbic system plays an important role in selecting and transferring information between our short-term and long-term memories. Selection and transmission of these two types of memories is done through the limbic system. In other words, the limbic system receives its information from different sensory areas such as the sense of smell (Schwarl, 1980; Schmidt and Threws, 1983). It is therefore understandable why the perception of certain scents can lead to the recall of certain experiences, or why when we experience childhood smells, we simultaneously perceive past emotions (Engen, 1982). Michel et al. found that where there is a floral scent, the responses to the environment are more favorable, and when there is a chocolate scent in the store environment, the favorable responses increase. On the other hand, responses are unfavorable when a scent that is inconsistent with the situation is used (Mitchell *et al*., 1995). As mentioned, scent can create emotional responses. On the one hand, certain scents can create a negative emotional state such as hostility, tension, confusion, and depression, and on the other hand, certain scents can create levels of happiness and improve a person's mental state (Hirsch *et al.*, 1995). Morrin and Rateshwar found that when there is a scent in the store space, customers spend more time there. In addition, scent increases brand retention by prolonging time and creating behavioral responses, even if the brand is unfamiliar (McDonnell, 2007). The presence of scent also leads to increased social interaction (Zemke *et al.*, 1995) and customers spend more money (Hirsch *et al.*, 1995). The neurons of the olfactory system end in the part of the brain that we know is the seat of emotions (Shepherd, 1983). Several studies in the field of mental health have shown that the use of aromatherapy has a positive effect on human emotions, since a large percentage of doctors' visits are due to stress-related problems, inhalation aromatherapy can be effective in reducing stress (Howarth and Freshwater, 2004).

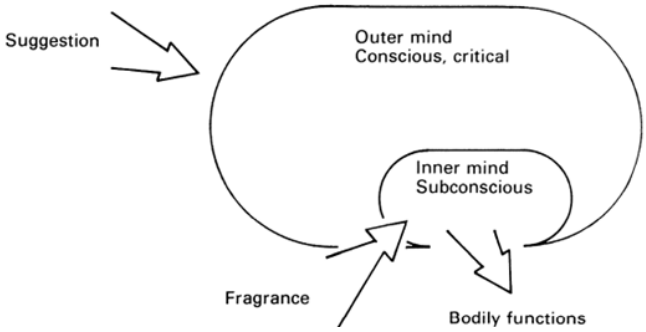

Fig. 1 - The relationship between conscious and unconscious mind (Van Toller & Dodd, 2012)

Iranian fragrances and its distribution in the country

Asia, as the world's largest continent, is one of the largest biodiversity areas in the world, which has the greatest plant diversity, especially in tropical and subtropical regions. Iran also has significant biological and climatic diversity, so that the number of its plant species is about 8000 species, of which more than 2000 species are medicinal and aromatic plants (Sefidkon, 2016). Ancient Iranians, by using their precision, elegance and aesthetic spirit, advanced in the industry of making aromatic oils to the point where they turned the common perfumery industry of that time into a fine art. Oriental perfumes are famous for their hot spicy notes. Some of the notes that make a perfume worthy of being "oriental" are cinnamon, cloves, vanilla, amber, sandalwood. In the book of aromatic plants, documents from the sources of Iranian medicinal and aromatic plants have been collected. These cases include 130 families of medicinal and aromatic plants, in which there are 2,250 species, of which 875 species are medicinal and 1,200 species are aromatic plants (Mozaffarian, 2011). By reading this book, among the genera and species found in Iran, those that were aromatic were selected in terms of the place of growth and geographical distribution, and they became the infographics shown down (Fig. 2). This map intricately weaves the distribution of Iranian aromatic plants and herbs into the heart of the fragrance personalization system. This visual journey reflects the diverse ecosystems across Iran, connecting the scents and colors of each region to an innovative fusion. From verdant valleys to arid deserts, this map embodies the authenticity and cultural richness that infuse the personalized fragrances, forging a genuine link between nature's palette and individual preferences.

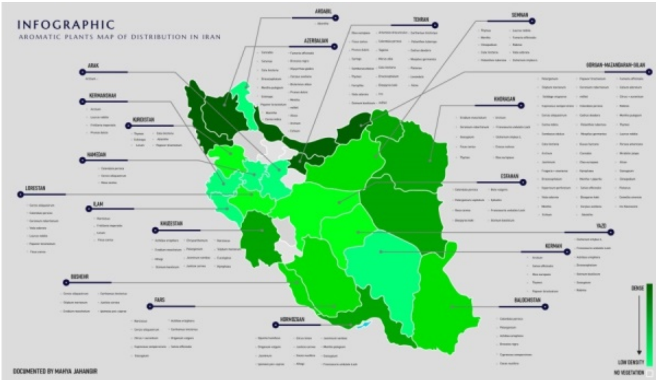

Fig. 2 – Map of Iranian aromatic plants distribution (Authors)

Design method

The IDEO method is selected as the design process for this study which consists of three main steps: "Inspiration", "Ideation" and "Implementation" (IDEO, 2015) (Fig. 3). The first part of the research focused on library studies. In addition, there have been observations and communication with users to receive more in-depth information. The second part of the research is dedicated to ideation and application of what was learned in the first phase through a practical project. In this section the online platform was designed that offers an interactive experience around perfume, with an association of colors-odors as a key role in it; In this step, the initial prototype and simulation were considered. In the third part, the simulated version of the PSS (product service system) was tested and evaluated with ten users.

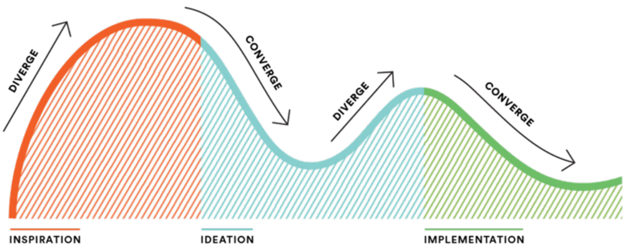

Fig. 3 – The IDEO method steps (IDEO, 2015)

The field observations were made in the authentic perfume stores in Tehran and the in-person purchase process at online shoping plateform was explored through direct observation with them and the results were used in the design process. In addition, a more detailed market analysis was conducted in different perfume sales platforms in Iran but also around the world. Namisanati, Elissa, Meisamatr, Atrsara, Ayliroma, Riiha, Atrpich, Mootanroo and Atrafshan were the Iranian online platforms which analysed for their contents and all the sensorial approches that they include in their user experience process. Fragranceby.me, Waft, Stéphanie de Bruijn, maison21g, Olfactory New York City, Scent Crafters, Scentiche, AuraVera, Rituals, Noordinaryscent, Scentbird and The Greatest Smell Ever were the international online platform in this analysis (Fig. 4). In the international platforms, the process of selecting and personalizing of perfumes is done intuitively and sometimes by relying on the visual memory of users while in the iranian platforms the personnalisation is done by brands, by temperaments, or sometimes by scent groups (cold, warm, mild). So it is necessary to create a suitable platform for logical and scientific selection and personalization of fragrances, especially for Iranian users.

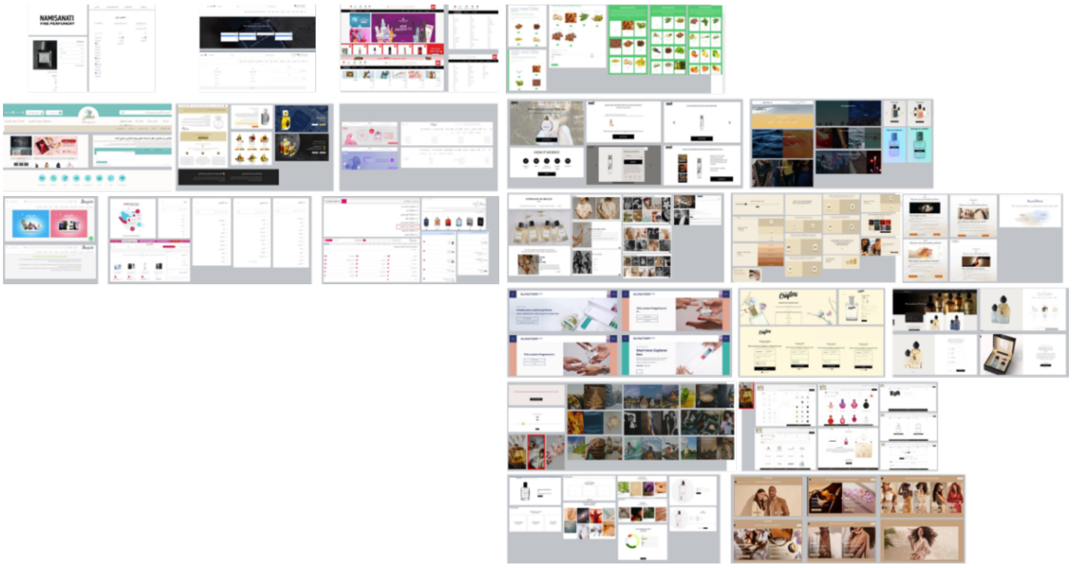

Fig. 4 –Tumbnail of market analysis of Iranian (left) and international online platforms around the world (right)

The card sorting, deep interview, wordcloud and magazine picture were used as the tools of gathering the information from user for creating the personas. The results of these tools were analyzed in two ways. One is the level of agreement of the participants in the scents of each family and the other is their actual familiarity with the cycle of scents based on colors (Fig. 5).

Fig. 5 – Four main families of the olfactory cycle (Leanna Serras, 2021)

The user experience design of 'Uroma' helps those who are amator or professional in this field to choose the fragrance they need from a different angle. Before finalizing the order, the user will asked to receive the Uroma cartalog, which includes four blotters (the main scent chosen by the user and three scents close to the one suggested by the perfume designers at Uroma). After receiving and choosing, the order will be finalized by scanning the QR code printed on the catalog (Fig. 6).

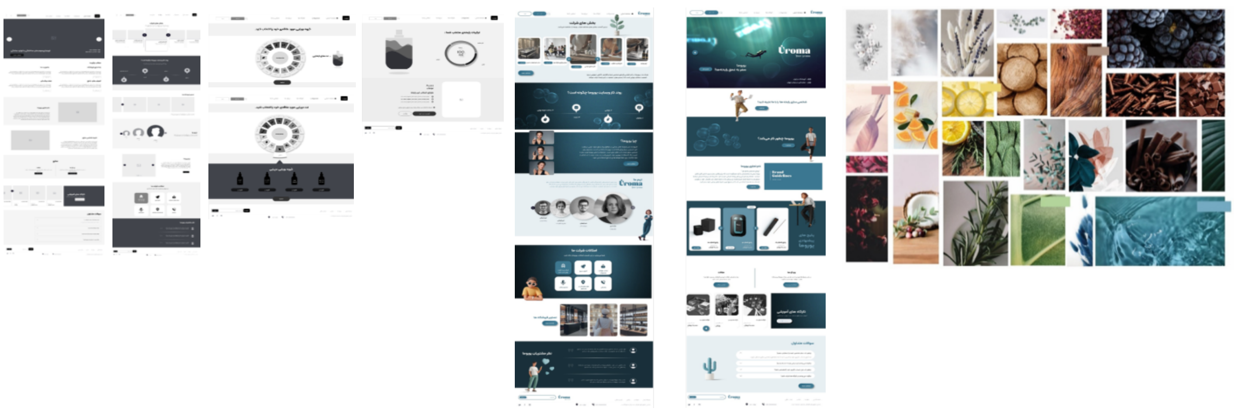

Fig. 6 – Designing the wireframes (left) and the final prototype (middle) based on users' moodboard (right)

Results

Floral notes evoke soft pastels, while oriental spices resonate with warm and rich shades. This mapping allows customers to visually connect with their olfactory preferences, making the selection process more intuitive and engaging. This online platform offers an interactive experience where users can explore fragrances by interacting with the fragrance and color wheels. By clicking on different segments of the fragrance wheel, users can instantly see the associated color spectrum.

Results

The practical part of this research is supported by the Embassy of Poland in Iran during the Polish Design Summer School at the University of Tehran. We thank our colleagues from the Instytut Wzomictwa Przemystowego specially Dr. Joanna Jurga who provided insights and expertise that greatly assisted the research.

Conclusions

The concept of this Product Service System redefines the way we connect with fragrances. By merging the fragrance wheel and color wheel, the fragrance selection is transformed into an immersive, intuitive, and personal experience.

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8. Color and Culture

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Queer Futures, Violet Futures: Queer Modernity Symbolism of Violet in West Culture

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Abstract

I bring together history of arts, gender studies and queer theories to analyse 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 the history of violet, I seek to highlight the manner in which this colour has linked modernity and queerness since the late 19th century, when violet tones became an important characteristic of a whole section of fin-de-siècle fashion, painting, and literature. Violet also has a long history with feminisms and queer movements in Europe and North America, from the Suffragettes' emblem to the non-binary pride flag. Going beyond the visible spectrum, ultraviolet light can also become a metaphor for a "beyond of gender" referring to the end of feminine/masculine and homo-/heterosexual binarisms. Could the colour of the future be violet? And is that future definitely queer?

Keywords: Violet, Queer, Modernity, Colour Symbolism, Synthetic Colorants.

Introduction: A modern take on violet

In 1856, the discovery of the synthetic dye mauveine by British chemistry student William Henry Perkin was a major turning point in the history of violet: until then its production had been difficult and expensive, but 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. Around the same time, the perception of homosexual men and women changed, under the impetus of sexology and psychiatry: violet then served to stigmatise these categories of people, who, through reappropriation, also used the colour as a cryptic queer emblem. The turn of the 20th century was also the time of feminist struggles for suffrage, with violet becoming a major emblem of one of the most famous of these groups: the Suffragettes. A few decades later, violet became associated with queer struggles, and in the 2000's with transgender and non-binary struggles and identities, with the view to overcoming the binarisms of masculinity and femininity, homo- and heterosexuality.

At the heart of a revolution in organic chemistry and the textile industry, while accompanying the feminist and queer movements and contributing to the emancipation of women and other gender and sexual minorities, violet is thus a colour of modernity, understood as a forward-looking ideology linked to the concepts of progress, innovation and emancipation. Going back over the last 150 years of the history of violet, my aim is to show its close link with modernity, in an attempt to determine whether or not violet is the colour of the future, and whether this future is definitely queer. To achieve this, I will use the various studies carried out on the violet, to create bridges between the material, social, cultural, artistic and cultual history of this colour.

Mauve Decade: Mauveine, Fashion, and Feminism

In 1856, while trying to synthesise quinine with the aim of finding an anti-malarial substance, Perkin realised that by cleaning up the organic waste from his experiments, he was obtaining a violet solution (Cova, *et al.*, 2017). The apprentice chemist had unwittingly developed the first synthetic dye, based on aniline, which he first called "aniline purple". Later called "mauveine", the success of this synthetic colour was dazzling, with Perkins borrowing money from his father to set up a factory in the year following its discovery, and also introducing the textile industry to the use of his dye, capable of coulouring wool and silk in different shades of violet (Fig. 1), which until then required expensive materials or processes (Beer, 1926). Fashion is therefore linked to the notion of modernity – even if it is sometimes opposed to it – "the strengthening of modern thought will be concomitant with the exponential development of the fashion industry, which will quickly affect the entire social body" (Liucci, 2008).



Fig. 1 - Silk purple dress, dyed with Perkin's aniline purple dye (*c.* 1870-1873); **Fig. 2** - Winterhalter, F. X. (1854) *Empress Eugénie* [oil on painting, 130,8 × 96,5 cm]; **Fig. 3** - Phillip, J. (1860) *The Marriage of Victoria, Princess Royal, 25 January 1858* [oil on painting, 103,2 × 184 cm].

Public demand for shades of violet know as mauve, lilac or heliotrope increased further under the influence of Eugénie de Montijo, wife of Napoleon III (Fig. 2), who found mauve to perfectly match for her eyes, and Queen Victoria, at her daughter's wedding on 25 January 1858 (Fig. 3), who wore a mauve velvet train on the advice of Empress Eugénie (Garfield, 2000, pp. 58-59). Violet hues were such a craze in 19th-century European fashion that historians sometimes refer to the European and North America last years of the 19th century 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 apprehending it as a disease whose "ravages are principally among the weaker sex" (Anonymous, 1859).

In the 18th century, European women were already the favourite customers of fashion retailers; the link between fashion and women continued to strengthen with industrialisation, from the end of the 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", and, above all, the creation of department stores made shopping the favourite 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 in a negative way, as it was also associated with "the vulgarity of cheap fashion, which the aniline revolution had precisely brought about" (Ribeyrol, 2021).

Associated with technological progress, violet is also associated with social progress, since it was 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 were quickly nicknamed the Suffragettes. In 1908, Emmeline Pethick-Lawrence suggested choosing colours to differentiate WSPU, of which she was an activist, from other organisations, and Violet, white and green were chosen, each for 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 one of the most distinctive features of most feminist demonstrations, worn by activists in the form of ribbons, scarves, medallions or clothing, and disseminated via posters, leaflets and banners (Fig. 4; Fig. 5; Fig. 6). Across the Atlantic, suffragist

Elizabeth Blackwell is said to have found a cryptic message in the choice of these colours, 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 the feminists of the period (Florey, 2013, p. 80).

Fig. 4 - Elsie Duval’s hunger strike medal (1912); Fig. 5 - WSPU postcard album (*c* 1911); Fig. 6 - WSPU rosette (*c*. 1913).

These explanations alone do not explain this choice of colours: there was also a form of pragmatism, so that all suffragettes could easily wear the WSPU colours. As violet was fashionable – as was green (Matthews David, 2017) –, all the women had at least one item in these colours in their wardrobes, so they could assert their political allegiance without making an expensive purchase (Heller, 2000, pp. 172-173). Relying on fashion, for which women were thought to have a natural inclination, 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 propaganada in the belief that ‘eccentricity’ would make the vote harder to obtain” (Ribeiro, and Blackman, 2015, p. 203). Moreover, by choosing fashion as a mode of communication, and using synthetic colours as an emblem, they were also positioning themselves as an avatar of modernity, associated with both novelty and progress, enabled by technological innovation.

Violettes Flowers: Fin-de-siècle, Decadence, and Homosexualities

These new shades of violet, which do not exist in their natural state, were particularly disturbing because of their synthetic production, that made violet such a popular colour in Decadentism, a fin-de-siècle literary movement (Palacio, 2011), named after the decadence of the Roman Empire (Ward-Perkins, 2005). The end of the 19th century had nothing in common with the turning point in Roman civilisation, but the feeling of decadence was felt enough to influence literary creation (Courapied, 2014, p. 48). For the historian Michel Winock, “[d]ecladence […] is 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 spleen so characteristic of the fin-de-siècle goes hand in hand with the fears engendered by the societal upheavals of the entry into modernity: the weakening of the Church, the social advances for women who were gaining access to new professions, the political organisation of the proletariat… (*ibid*.). The ambiguous term “decadence”, laden with negative connotations, was also used to stigmatise behaviours deemed immoral or unhealthy as a result of modernity and its progress (Kopp, 2019), including male homosexuality. It becames the object of moral, psychiatric and legal studies, and was thought to be a symptom of industrialisation, which risked depopulating society and thus 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 thus made the homosexual aesthete and the androgynous “a widespread subject, a constitutive element of Decadence” (Palacio, 2011, p. 188).

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Decadentism then took the form of a revolt against nature in favour of art, or even the artificial, which was crystallised by the many references to artificial flowers, mass-produced at the end of the 19th century and often coloured surrealistically with synthetic dyes. Literary researcher Romain Courapied points out 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, that “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 taking place at the Salle Wagram, a guinguette frequented by homosexual men, young ephebes “had sown violets” on the tables (1905, p. 105). For Courapied, “the colour violet acts as a paradoxical indicator of a perverse content integrated into pleasing aesthetic forms” (2014, p. 409-410), referring to the liminal symbolism of violet, referring to the twilight hues when the sun sets; but it could also evoke disease or putrefied flesh, thus echoing masculine homosexuality as perversion.

Far from being just for men, violet was also, and even more so, a reference to lesbianism, particularly through the lesbian writer Renée Vivien. Called the “Muse of violets”, she was devoted to the spring flower that adorned her letterhead and books (1903), and that dotted her own writings. Her obsession with violet was undoubtedly linked to her youthful love Violet Shillito who died prematurely. This association between violet and lesbianism is perhaps even more recent, since 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 in particular for the Sapphic scenes it describes.

Indigomania: Impressionnism, Artificiality, and Degeneration

Deeply influenced by colour theories that had proliferated since the publication of Isaac Newton's *Optics*, the Impressionists played on 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. 7; Fig. 8) 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 the newspaper 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 as they were now obtained synthetically using aniline (Ribeyrol, 2018).

Fig. 7 - Monet C. (*c*. 1915-1926), *Nymphéas* [huile sur toile, 200 × 426,1 cm]; **Fig. 8** - John Singer Sargent J. S. (*c*. 1885-1886) *Carnation, Lily, Lily, Rose* [huile sur toile, 174 × 153,7 cm].

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Taking up *The Punch*'s pathologising approach to the popularisation of mauve among women (Anonymous, 1859), art critics viewed Impressionist painting less from an aesthetic or artistic angle 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 the neurologist Jean-Martin Charco and the ophthalmologist Xavier Galezowski (*ibid.*, p. 104), Huysmans associated the Impressionists' "manic" use of violet with neurotic-type psychological disorders, which would make the retinas sick, limiting the perception of green in favour of blue and violet (*ibid*., pp. 90, 104). By associating Impressionism with mental disorders, he joined the idea of the decadence of fin-de-siècle society and the degeneration of art described by the physician and art critic Max Nordau, who saw in industrial acceleration and modern art a degeneration of society (1882, pp. 30-31). The considerations given to the Impressionists are therefore similar to those given to the Decadents, at a time when sexology was emerging and homosexuality was becoming an object of psychiatric study (Courapied, 2014); the difference is that the Decadents took a stand on this theme, whereas the Impressionists never addressed it, or too subtly.

Ultraviolets: Queer Communities, Activism, and Social Change

The late 19^{th} century saw the rise of 'modern homosexuality', with lesbians and homosexual men becoming increasingly visible – sometimes perhaps unwillingly – as a result of growing medical interest, and the emergence of a 'homosexual world' in the big cities – notably Paris, London and New York – which was still, however, an underworld (Latimer, 2005; Revenin, 2006). Violet could then be used as a code to signify homosexuality and to identify each other as homosexuals, without this sign necessarily being understood by heterosexuals. After the First World War, these 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" was used to designate an effeminate man (Pollock, 1935, p. 115). The homosexual meaning of violet then became popular in the 1930s, 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 who had come to protest a homophobic article (Bideaux, 2023a, p. 425).

Meanwhile, violet remained a feminist emblem in Europe and North America, and still is today. Creating a filiation with the Suffragettes' emblem, the feminists of the 1960s-1970s gave it another meaning: as violet is a mixture of blue and pink, the traditional colours of layettes, it signified the desire to do away with gender stereotypes, and the goal of gender equality (*ibid.*, p. 304). Choosing violet was also a way of differentiating themselves from other political movements that already had their own colour emblem (red for communists, black for anarchists…). Splits within feminist movements were even symbolised by different shades of violet: the lesbians of the National Organization for Women (NOW) were described as a "lavender menace" by its president Betty Friedan, who feared that their masculine appearance and hatred of men would undermine the movement (Brownmiller, 1999, p. 82), while the black feminist activist Alice Walker associated violet, on the one hand, with a "white feminism" that rejected the integration and intersection of gender and race issues, and, on the other hand, purple with an intersectional feminism promoted by black women, which she called "womanism" (1983, pp. XI-XII).

At the end of the 1990s, the symbolism of violet became more queerised, incorporating new symbols that were no longer limited to homosexuality. It now includes bisexuality, with the bisexual pride flag consisting of three coloured stripes: a pink stripe signifying homosexuality, a blue stripe signifying heterosexuality and a violet stripe – a mixture of the first two – to symbolise bisexuality (Fig. 9; Page, 1998). In the 2000s, violet also became the emblem of transgender struggles and identities, chosen again for being the mix of the traditional "pink for girls"' and "blue for boys" in one of the trangender pride flag (Fig. 10; Pellinen, 2002), and in the following decade it appeared alongside yellow, white, and black in the non-binary pride flag (Fig. 11), then representing people in between masculine and feminine gender identities (Rowan, 2014). The violet then sort of mutates into ultraviolet, a light with a wavelength outside the spectrum visible to the human eye, becoming a metaphor for a search for a "beyond gender" that refers to the end of feminine/masculine and even homo-/heterosexual binarisms.


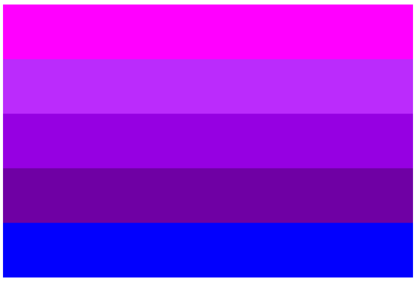


Fig. 9 - Page, M. (1998) Bi Pride Flag; **Fig. 10** - Pellinen, J. (2002) Transgender Pride Flag; **Fig. 11** - Rowan, K. (2014) Non-binary Pride Flag.

Conclusions: Twilight Visions of Queer Futures

Violet symbolically associates, on the one hand, technological progress, artistic innovation and the renewed novelty of fashion, and, on the other hand, new conceptions of homosexuality, struggles for the rights of gender and sexual minorities, and the possibility for women and queer people to live freely. Since the end of the 19th century, it has been the "subversive color of modernity", as much as that of queer utopian perspectives. Even today, violet is used to evoke better futures, where progress is combined with the development and freedom of the individual; it is thus the color most associated with cyberspaces – now called metaverses –, perceived as a liminal color, the fusion of the digital world – symbolized by the blue of the internet – and the physical world – symbolised by red blood of our flesh (Bideaux, 2023b). Imagining the metaverse in violet is also seeing a digital worlds as queer spaces where anonymity allows one to free oneself from questions of gender or sexuality to fully experience one's individuality (Lau, 2014).

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, and, as we have seen, the colour that symbolically plays with the limits of femininity and masculinity, of homo- and heterosexuality. As a colour associated with modernity, violet also marks the transition between the present and the future, but it can be both a queer utopia as well as a straight dystopia. Indeed, modernity has not always been synonymous with queerness: the discovery of mauvéine served to stigmatise bourgeois women (Ribeyrol, 2021), advances in psychiatric medicine accompanied the oppression and repression of homosexuals (Courapied, 2014), certain feminist achievements may have overlooked racialised women (Walker, 1983) and transgender women (Worthen, 2022), just as gays and lesbians may lack solidarity with bisexual and transgender people, or even discriminate them (Weiss, 2011). If it seems to me that modernity cannot be achieved without participating in the emancipation of everyone, then there is no guarantee that the future will be queer; but if we envisage it rightly, then violet – and even more so ultraviolet – looks set to remain the symbol of queer modernity – at least in the West.

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The ceaseless flow of colour

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Extended Abstract

This paper explores the way colour is used in the works of three artists living in Zürich, Switzerland: the limited palette of Shirana Shahbazi's artworks; the enlarged palette of light artist Christian Herdegg; and, the exclusive palette of artist Marco Ganz. The artist Marco Ganz creates compression-cut and flocked foam objects, ultralight wall sculptures made of carbon fibre laminate, CNC-milled aluminium sculptures or nine-meter- high high-tech wood sculptures – most of them are highly glossy and saturated monochromes. In his recent print work, exclusive colour palettes are used. "Car Color Culture" (2013) uses metallic car paint colours. "Inkjet" (2014) represents a beautiful colour spectrum in the panoramic format that diminish towards the ends. And "Cibachrome" (2015) includes fifteen saturated colours on a black background. Their names refer to original Lee filters. The light artist Christian Herdeg won the Lifetime Achievement Award of the Canton of Zurich in 2021. Trained as a professional photographer, cinematographer, and lighting technician, his light sculptures belong to the genre of lyrical minimalism as they interact with the surroundings in a silent and poetic way. The primary material is his "coloured pencils," i.e., fluorescent lights in around 300 different shades that he developed in the 1970s. His glass tube collection is stocked in drawers reminiscent of oversized boxes of coloured pencils. The elements argon and neon lead him in his ongoing investigation into light as matter. One of his latest commissions, however, uses LEDs and includes three light sculptures for large-scale interior spaces of the new building of the Cantonal Hospital in Chur. The light artist opted for three ellipses, whose geometries resemble the orbits of celestial bodies. The first sculpture with its blue light 'Baltic Sea' on the lower surface and red 'Uluru' on the top creates a distinct atmosphere. And, finally, Zurich-based photographer and artist Shirana Shahbazi was born in Tehran in 1974 and won in Switzerland the prestigious award "Prix Meret Oppenheim" in 2019. In her photographs she documents and captures moments of daily life. She then translates those photographs that matter to her in different techniques (c-prints, lithographs, silkscreens). Using a limited palette (monochrome print, bichrome combinations) the resulting effect is a construction of an alienated, fictional and sometimes phantasmagorical world. She modifies colour and alters not only the viewer's perception of reality but also raises the philosophical question of time, location, testimony, representation, and appearance. For some exhibitions, she also determines the colours of the walls (e.g., night blue, traffic red, silver grey) and, in this way, creates ephemeral art installations. Each artist has his/her own way of dealing with colour, whereby the ultimate mystery cannot be revealed with words.

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Persian blue. At the origins of colors in Islamic architecture. An example: the Jameh Mosque in Isfahan

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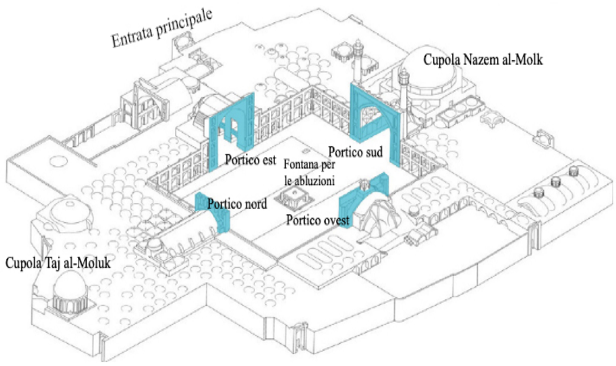
Abstract
In Islamic architecture, colors are of fundamental importance: they are used in religious and cultural settings such as mosques, schools, libraries and public gardens. Colorful elements in blue, green, yellow, red and white are often used in the interior and exterior decoration of these buildings. Color as an interpretative element or as a "key to interpretation" is given particular attention in the decoration of the Great Jameh Mosque of Isfahan, the most important architecture of the Seljuk period in Persia (1038-1118), subsequently modified and expanded in the following centuries. In this article, we want to study the effect and meaning of colors in the decorations of this place of worship. In the Friday Mosque (as it is also called) the cultural identity and traditions of Islamic thought are shown in the decoration of the interior. In this article, we would also like to explain the influence of Sufi mystical thought on the use of symbols in decorations and in the use of color.

Keywords : Isfahan Mosque, Jameh Mosque, Islamic decorations, Sufi thought



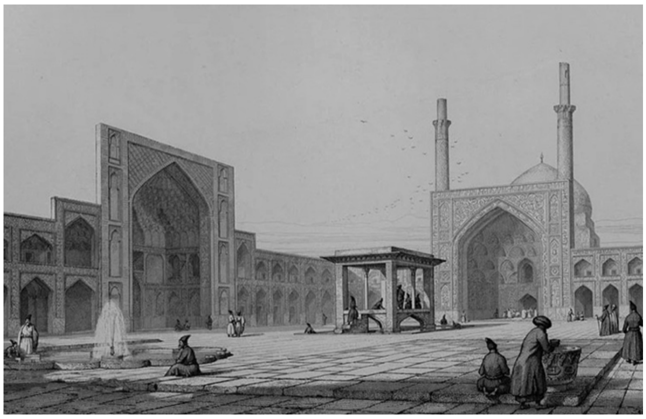


Fig. 1. Axonometry of the Isfahan Jame Mosque with the location of the arcades and domes. Fig. 2. Great Friday Mosque in Isfahan, from "Voyage Pittoresque di Persia", engraved by Auguste Guillaumot, edited by Lemercier, Paris, 1856.

Brief history of the Jame Mosque of Isfahan

The Jame Mosque of Isfahan, also known as the Friday Mosque of Isfahan or Jame Atiq Mosque, is a historical monument whose construction seems to date back to the 1st-2nd century of the Hijra (about mid-8th-9th century) at the time of the Abbasids. Adjacent to the Mosque, the large market of Isfahan has formed over time, in an area densely saturated with buildings built over the centuries. In plan, the Jame Mosque today has a rectangular shape, with at least ten main entrances, but it is the result of a series of unifications of courtyards, arcades, libraries, etc. (Fig. 1).
Islamic tradition has it that the Jame Mosque is one of the oldest historic buildings in the Muslim world (Fig. 2). Traces of pre-Islamic buildings dating back to the Zoroastrian era were found during archaeological excavations in the area of the complex. According to some theories, researchers and archaeologists believe that there was probably a fire temple in the place, certainly datable to before the Arab domination of Iran, perhaps from the Sasanian period (224 AD - 651 AD) on the basis of a discovery of the remains of some columns with decorations.
After the arrival of the Koranic culture in Iran and the establishment of Islamic governments, the construction of the mosque was begun between the 1st and 2nd century of the Hegira (about half of the 8th-9th century) at the time of the Abbasids. The Mihrab and a large part of the wall towards the

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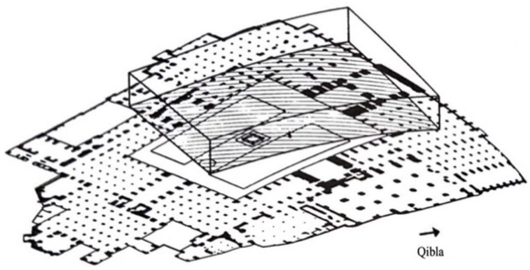
Qibla of the old mosque were found under the floor of the south chapel of the present mosque. In the 3rd century of the Hijra, the primitive Mihrab was destroyed and the direction of the qibla was changed (Fig. 3). A library was added to the mosque, where the ancient books and sacred texts were kept. In the year 226 of the Hegira, the old mosque was destroyed and on its ruins a larger mosque was built of almost ten acres, with a pillared nave plan, with a gallery in the center and chapels around it. In the 4th century of the Hegira, during the Buwayhidi reign, an opening was added to the naves, making the central one smaller, and the columns of the facade were also made. In the 5th and 6th centuries of the Hegira the mosque was transformed by adding four porticoes. In this way, the continuous and simple space of the naves and courtyards with porticoes and two domes was separated (Fig. 4).



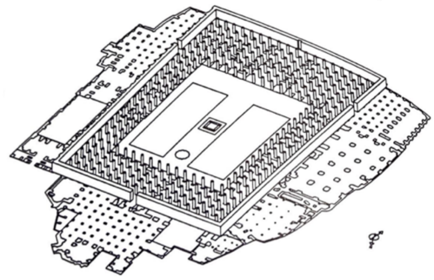


Fig. 3 - Isfahan Jame Mosque, schematized the site of the mosque between the 1st and 2nd century A.D. Fig. 4 - Isfahan Jame Mosque, during the Buwayhidi reign (10th-11th century).

In the years 473 and 481 AH, the beautiful domes were built in the southern and northern parts that of Nizam al-Mulk and the other of Taj al-Mulk. Henceforth, having four porches in the mosque became one of the key features in building mosques in Iran.
The main additions and modifications that have given the current appearance to the Mosque are due to the Buwayhid (10th-11th century) and Seljuk (11th to 14th century) periods. During the Ismaili era, due to popular protest against the Shah, the Jame Mosque was set on fire and many parts were damaged, but promptly restored. Other important transformations took place during the Safavid period (16th - 18th century) where many parts were modified or restored. The Khorasani style appeared in the first century of the Hegira and continued until the fourth. These formal characters take their name from the territory of Khorasan where the main manifestations of this style took place. This region is the cradle of the first examples of Islamic art and architecture; from there it spread to cities such as Damghan and Yazd. From the point of view of Niarshi (in the Parsi dictionary, Niarash is the science of building structures. This is one of the fundamental principles of Iranian architecture, used in the past, now fallen into disuse), the Khorasan style derived in part from the older partisan style. In the planimetric layout the Jame Mosque of Isfahan seems to derive from that of the first mosques, for example that of Medina.

Islamic architecture between art and spirituality
In the history of art and culture, the meaning of the word "art" has always been associated with a sort of inspiration and/or enlightenment, as a manifestation of human genius, an internal sensation stratified in each of us, which is the basis of the secret of creation, which has always been in a profound connection with the soul of the artist, who at the top of the creation of the work will be sublimated with the achievement of this position. Today, wherever remains of civilization are found, the role of religious teachings and spiritual inspirations that guided that civilization and conditioned the aspects of art emerges at the same time. Muslim architects and artists have always tried to create buildings and their parts, especially mosques, in such a way that they reflect and manifest the relationship between man and God on the one hand and between God and man on the other. More than other arts, architecture has been able to show the motif of excellence and the idea of immortality and the desire to ascend towards the sky. Architecture plays an important role in defining the image and integrated vision of the soul of an element and the relationship with the

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feeling that human beings have towards the state of the world and the environment in which they live: more than any other art, architecture is connected with the feeling of emotion and thought of the human soul.

The meaning of spaces and ornaments in Islamic art

The sense of place in relation to the spirit of the *"genius loci"* has always been a term used in history to indicate the performance of rites, the devotional movements that users had to perform in religious ceremonies: to have a lot of attention and respect, (Rahimian, 2005). The ornament in Islamic art, contrary to a superficial opinion that considers it only a means of embellishment, has a symbolic identity, a metaphor that reveals the truth, a truth that tends towards the ideal, obsessively sought by every architect. But ornament is also an aesthetic element. Colors have a soul and their own spirit, colors are words and words explain, give meaning to things: from the green of the forests, to the blue of the sky and the seas, from the clarity of the raindrops and the whiteness of the snow. Colors speak to the soul and interact with the mysterious world that surrounds us, they communicate emotions, sensations, moods: "the colors that people wear, draw and paint also tell of other ears from within" (Kashani, 1991, 14).

Inside the Mosque, light, evident and hidden, plays a fundamental role; an extremely varied and complex sample of lights and shadows that occurs inside the colonnades, in the gaps between one room and another. These visual effects create areas invested by full light that are placed next to other parts in full shadow, almost dark in an aura of ambiguity and darkness (Figs. 5, 6). In such semi-dark spaces where the understanding of the environment is not possible through the physical and material visual senses, the mind understands the spiritual nature of the space with increasing intensity and depth, because under such conditions the five senses, which are immaterial in nature, are more active.

Fig. 5 - A Shabestan ceiling. Fig. 6 - Hypostyle hall. Lights and shadows in a Shabestan's mosque.

But even among the various samples of decorations there are some that are more evident and others that are hidden. The decorative motifs used in the bodies of the different spaces of the mosques have given the works of Islamic architecture a special look and distinguish them from other western places of worship. Islamic motifs, which are basically a sort of abstract decorative art, depict a concept in an immaterial way which, combined with color, stimulates the public's taste and curiosity to reflect and think when in front of it (Navaiy and Haj Ghasemi, 2011, 173). Since the Seljuk period, the Iranians had mastered the technique of coating clay decorations in turquoise, blue and green with enamel. They are the main colors of Islamic art (Stirlen, 1998: 88). The blue and turquoise colors are used in particular for Mihrab and Shabestan (the underground space usually found in mosques, houses and schools in ancient Iran) and for the external cladding of the domes; these colors are among the oldest and easiest to produce and were obtained in the kilns by firing the ceramic. The decorations and color tones in the interior spaces of the mosque, such as the naves and domes, often present notable differences compared to the courtyard bodies, which are sometimes enriched by a profusion of colors and decorative motifs. Indoor spaces are usually adorned with earthy tones of brick, and the nature of such colors helps to give the environment an atmosphere

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that lends itself more to contemplation and meditation. The prevalent use of a single material, brick, in the different sections of the domes (Noia, 1994: 160), has created an austere and serene atmosphere, which invites the faithful to reflection rather than ecstasy. The predominant color overall is light blue, but there is no shortage of turquoise accents which, following the vertical lines of the structure, seem to extend like an extension of the vast blue expanse of the sky; the monochromatic internal spaces of the floor recall the tones of the soil, of the earth. This architecture is closely connected and compatible with the nature of the places, especially with the desert. The contrast between the colorful architecture in the courtyard and the earth and brick architecture inside leads to deep reflection. When we interact with a space over time we acquire a sense of belonging, this space becomes peculiar to us, a sort of feeling of familiarity; on the contrary when we move away from it we feel a feeling of nostalgia. This suggests that color in architecture has the ability to create memories. Texture and color affect the visual impact, scale and quality of light reflection, and if the design is done without color co-ordination, the character of the place will be lost. Color changes the environment, has the ability to create memories for human beings, and creates changes in human vision and behavior, and this issue has a nostalgic feeling for human beings. Color invests the architectural space with a feeling that can be described as a bond or, more specifically, a sense of affinity with that particular place, essentially creating a sense of belonging to it.

Color and its symbolic meaning in mystical thought

Highlighting empty spaces, indicating directions, showing the principle of repetition or duality, revealing dynamism and stillness, all of this can be indicated and/or revealed by the presence of colors and decorations. These inserted in a spatial context, strengthened by the light and by the characteristics of the materials, create and highlight the perception of sensations, such as the sense of solitude, of concentration or the aura of mystery that is sometimes perceived when entering the mosques: “The vision of the Sufis towards the world of nature and sensations is basically for a vision based on the code.” (Pour Namdarian, 1997. 70). This point should not be overlooked: the Sufi code refers to any sign and symbol and goes beyond apparent meanings.

Sheikh Eshraq Sohrawardi (second half of the sixth century), whose thought is also based on the philosophy of light, in the book Hikmat Eshraq says: “The luminous nature of God gives a stable light that manifests itself and gives life to everything in his light (…) He brings into existence and everything in the world is caused by the light of his nature, and the beauty and perfection of everything is a gift from his generosity and grace, this is the illumination of salvation”. We consider it highly probable that Shia mystical thinking influenced the symbolic use of blue decorations in the ornaments of the Jame Mosque; in fact, we must consider that color is among the main parts of Iranian art and architecture and is certainly among the elements on which the understanding of the inner meaning of Iranian art depends. It should be noted that the colors used in Iranian painting, in particular gold, silver, blue and turquoise, are not an arbitrary choice of the artist, but are the result of a profound mental and spiritual elaboration which passes through the eyes and heart and represents an exemplary world, in balance and harmony and which, according to the opinion of Islamic sages such as Mulasadra, also embodies the seat of Paradise. Sufi philosopher Ghazali believes that the relationship between the external world and the internal world is like the relationship between shell and core, between darkness and light (Figs. 7, 8, 9). In the world of mysticism, blue is mainly used as a symbol of the color of the Sufi cloak, and remains the main color with which the Sufi dress is characterized, in the work of Najm Kabri and Alaa al-Doulah Semnani we read: “In in this way the color of the blue robe is suitable for those who are still in the early stages of the mystical life” (Corbin 2013, 228). Ebadi also states in the book “Al-Tsafiyah Fi Al-Ahwal Al-Musufah”, in addition to the clothing customs of Sufis, that “from the point of view of Sufis, this color is a symbol of liberation from the beginning of conduct” (Ebadi 1989, 245).



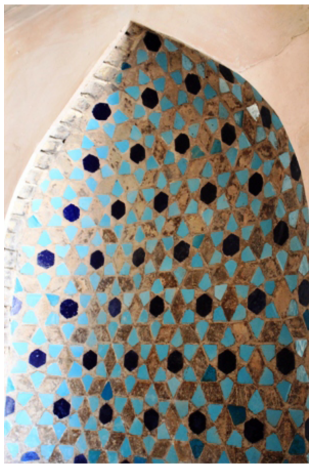

Fig. 7 - Sahib porch on the south side. Fig. 8 - West side porch. Fig. 9 - Entrance to the Mozafari school.

But the most important point is that the mystics identify in this blue vestment two categories of distinct colors: "… Najm Kabri recognizes two categories… He clearly testified: one is of azure color (dark blue) and the other is azure (azure sky, lapis lazuli)" (Corbin 2000, 228). Since "the walls of some mosques are covered with glazed tiles or fine plaster, this is reminiscent of hijab encryption" (Burckhardt 2011, 147). Considering now that "architecture and its elements can be useful only to the extent that they prepare the right context for this process (spiritual evolution and journey to God)" (Noghrekar 2008, 479) this can be argued as mosques, in Islamic religious creed, are precursors and through the journey of the soul: "The discovery of intuition and silence is in the color blue" (Schoun 2011, 89). With the appearance of Muhyiddin at the end of the 9th century (Timurian) we find the apex of the development of the epistemological dimension of Islamic mysticism. In this period, practical mysticism became independent of theoretical mysticism, and ontological analyzes were presented to mystical authorities and covens. So that "for the first time in the history of Sufism and Shiism, mixed movements of the two appeared" (Al-Shaibi 2008, 166). Therefore, in the Timurid period, with the growth of mystical thought, blue tiles were also used for the domes and in the external spaces of the building (Okane 2007, 225). However, the "color combination of turquoise and azure with white is the favorite combination of 8th and 9th century artists" (Haj Ghasemi 2011, 285).
Iranian architects have worked to demonstrate how much "the characteristic of traditional arts is their objectivity" (Aldomedo 2010, 248). "Islamic art and architecture of this era are symbolic sources from the multiplicity of the external world to the unity of the internal presence of Allah" (Khatami 2011, 198).

Decorations: models and examples

Geometric motifs and decorations based on plant models are both used in the Jame Mosque (Figs. 10, 11). The use of Eslimi plant motifs in the building is much less than the use of geometric ones, which are subtly employed in the decorations on the surfaces of the south porch and in the large portals on the four sides of the courtyard, although always in combination with geometric motifs.

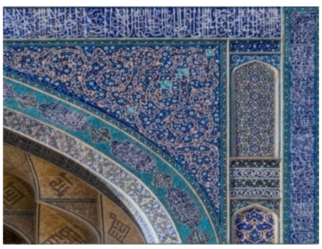


Fig. 10- Mix of Eslimi and Khatai lines on the sides of the arch of the south porch. Fig. 11- Geometric motifs in the west porch.

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The inlaid plant decorations are limited on the external central parts facing the courtyard, they are often the result of two or more motifs of intertwined nets, namely Eslimi and Khatai (Nawai and Haji Ghasemi, 2011, p 264). Eslimi decorations are inspired by nature and are a sort of plant motif based on curved lines and spirals. There is movement and fluidity in the elements of the Eslimi plant motifs, but thanks to the symmetrical scheme, the whole results in a harmonic and balanced stability (Table 1).

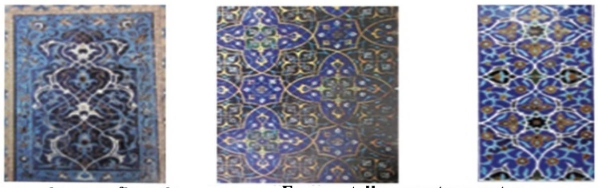
	Tecniche	Figure
1	Simmetria asiale	
2	Decorazioni	 Forma losanga floreale Forma stella a quatro punte
3	Continuatità lineare	

Table N. 1- Techniques of order and static nature of the decorations in the Jame Mosque of Isfahan.

Naqsh Khatai is the second motif of traditional Iranian arts: “The comparison between the Khatai and Eslimi forms shows that the common points in the external and internal rotations and folds of these two motifs are nothing but the common root in their creation and function” (Zhoule, 2016).
At the origin of the Khatai motif “… is a flower stem that moves across the surface in a balanced way and on the initiative of the artist, all kinds of abstract flowers, leaves and buds are scattered on it” (Riyazi, 1996, 60) elements that are reinterpreted in groups or individually such as for example the flower of Shah Abbasi. “If we consider Eslimi’s motif as an abstraction of a tree drawing, we should also consider Khatai’s motif as a diagram of the abstraction of a branch, bush, flowers, leaves and buds. To simplify, the Eslimi model can be traced back to the image of a tree, its trunk and its branches; the Khatai one to the winding and sinuous motifs of flower stems” (Azhand, 2013, p100). Iranian artists have used the Naqsh Khatai motifs in various applications: for the weaving of fabrics and carpets, for embossing, niello or chased works, in painting, in ceramic plates, in majolica tiles, in carving, etc. (Ajand, 97:1393); “It should be known that the Khatai designs of the carpet are more detailed and have more components and more diverse colors” (Aqdasiyeh, 32, 1336), (Figs. 12, 13,14).

Fig. 12- An example of Khatai designs with Shah Abbasi flowers. Fig. 13- Tasheir carpet with Khatai motifs, master Safdarzadeh Haghighi, Hafta Gallery. Fig. 14 - Eslimi in the angular motifs with bergamot (Toranj).

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After becoming familiar with this pattern, Iranian artists also applied Khatai in the illumination of ancient books and on the leather covers of ancient texts., although with modifications
The Khatai motifs in the Great Mosque of Isfahan are mainly used in the fronts of the Mihrabs, in the decorative slabs, in the columns and sometimes as a decorative fixture of the facades of the porticoes. Therefore, Eslimi and Khatai motifs can be considered a significant part in the decorations of the Safavid period. In the Sangab (ablution basin) of the north portico, the arrangement of flowers is divided into eight parts by Khatai flowers on the base of the circular space; this constitutes the central part of Sangab while on its edges we find short poems and verses from the Koran carved. At the end of the south porch hall, on the edge of the marble threshold, on both sides of the porch, there are two beautiful tablets made of mosaic tiles in small glazed tiles, with Eslimi and Khatai designs. In these plates, the Eslimi motifs together with the Khatai flowers cover the entire frame and the space obtained is similar to that of the decoration which includes a vase from which all the Eslimi branches have grown (Fig.15); the same motif is repeated in the altar of the south portico. But the composition of the vase with flowers used in this composition is completely different from the other one represented in the terminal slab of the south portico. Furthermore, the motifs in the central part are enclosed in a rhomboidal space. In this Mihrab, the spiral Eslimi motif is abundantly used at the top of the vase and above the floral motif, creating a unique combination (Fig.16). In describing the forms used in this mosque, the Mihrab patterns of the south side of the western porch are very unique and unique in designs and colors, beautifully done. In this, the rear part of the arms of the internal arch is decorated with Eslimi motifs that come out of the dragon's mouth with sinuous motifs. In the internal part of the intrados of the Mihrab arch, we find: the Shamseh motifs and decorations (a compositional decorative system that draws its symbolic matrix from the solar disk), the Eslimi and Khatai motifs that decorate glazed multicolored ceramic tiles. In the central part of the Mihrab there is a closed scheme of geometric decorations which are set on a quadrangular mesh; from the beginning to the end of the margin box we find a series of inscriptions (Fig. 17)
The Jame Grand Mosque is a museum of Eslimi, Khatai and geometric motifs with composite structures of singular beauty. It must be said that the uniqueness of the motifs of each section does not mean that they do not complement each other. The variety of decorations in the Mosque include changes in the details of the flowers, the way the Eslimi stems rotate, the number of stems, color and size. The Mihrab motif of the dome of Nizam al-Mulk, which was probably decorated with tiles in the 10th century of Hegira during the reign of Shah Tahmasib I, is one of the examples of the different compositions of the Eslimi motifs in this mosque (Fig. 18).

Fig. 15- Khatai flowers in the center of the Mihrab of the southern side of the Sahib side. Fig. 16- Eslimi stem and khatai flowers in the end plate of the tablet of the west porch. Fig 17- Khatayi flowers in the decorations of the south altar of the west porch. Fig. 18- The Eslimi turn in the decoration of the altar under the dome by Nizam al-Mulk.

The Jame Mosque has 10 entrances, of which only 4 (Saqakhane, Bab al-Dasht, Abu Ishaqiya and Taj al-Muluk) have tiles with fractional patterns. The first entrance is the Saqakhane entrance (in traditional Iranian architecture, this term referred to small spaces in public streets that residents and traders created to distribute water to thirsty passers-by). The cladding techniques used in this entrance include the Maqali tile technique (in this technique, the tiles are cut into square, rectangular, rhomboid and triangular shapes. These elements are used both in the facade (Fig. 19) as

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a combination alongside the bricks, or are used to put them together to represent letters and expressions in a rational line) and Haftrang (Fig. 20). The second entrance is Bab al-Dasht, which is located on the west side of the Mosque. This entrance also has mosaic technique coverings on the façade and Maqali technique on the plinths (Fig. 21). The third entrance, that of Abu Ishaqiyya, has an inscription in plates with white Thuluth characters on a blue background made in the 19th century. The technique used in the decoration of this entrance is the rational tiling (maqali) which is implemented in the entrance (Fig. 22). The fourth entrance is the Tajalmolek entrance, which is located on the north side of the Great Mosque of Isfahan (Fig. 23). The tile inscription of this shrine is dated 768 Hijri (c. 1366) and its tile decoration was done in the technique of Maragh, Maaqli and Paran glaze (Paran glazed tiles are made by removing a of the glaze and revealing the beige color of the tile surface).

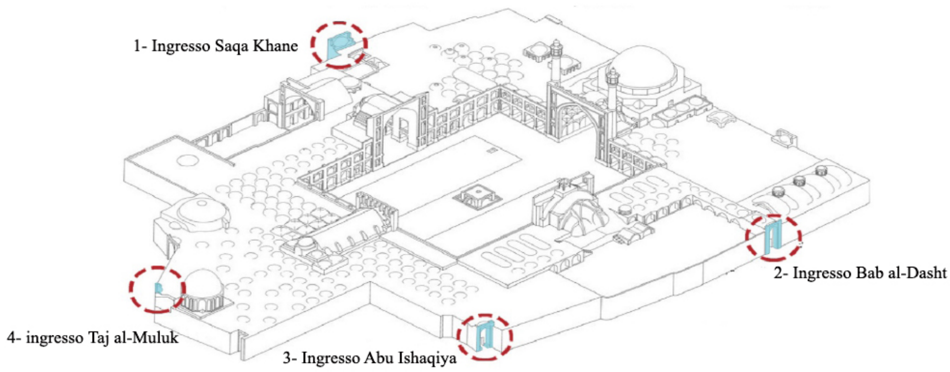

Fig. 19 - The location of the entrances of the Isfahan Jame Mosque, documents available in the exhibition of the Isfahan Jame Mosque (2018).




Fig. 20- The Saqakhane entrance. Fig. 21- The Bab al-Dasht entrance. Fig. 22- Abu Ishaqiya. Fig. 23- Taj al-Muluk. The entrances of the Jame Mosque of Isfahan.



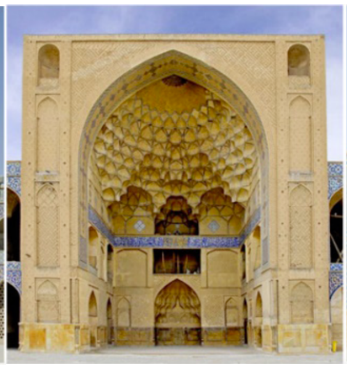
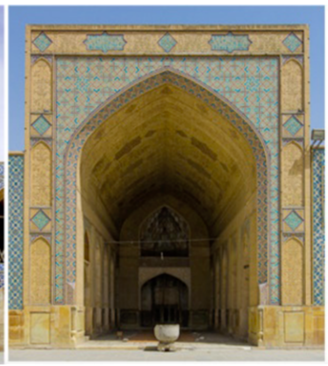

Fig. 24- South portico (Sahib). Fig. 25- West portico (Maestro). Fig. 26- North portico (Darvish). Fig. 27- East portico (Disciple)

Conclusions

We have tried to describe in this contribution some of the main characteristics of the decorative apparatuses present in the Jame Mosque of Isfahan; we realize that the complex and varied collection of ornamental models deserves further study and insights in order to create a wider abacus of decorative types.

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9. Color and Education

 ISBN 978-88-99513-22-1

The project of a tool that uses Fechner's colors for the foundations of lighting and color design.

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Abstract

This article presents the project of a tool aimed at elucidating the nature of color as a psycho-perceptive sensation existing solely within the human mind. Aimed at novice designer, this tool delves into the intriguing phenomenon of Fechner's colors and their implications for our understanding of color perception. The phenomenon of Fechner's colors is first introduced by explaining its importance for understanding the psycho-perceptive nature of color. We then delve deeper into the current possible scientific explanations underlie Fechner's colors visual perception. The design of the experiment is then illustrated, carried out using a black box under controlled lighting conditions, intending to be able to directly observe Fechner's colors rather than observing a representation of the experiment on the computer screen, which could make some subjects doubt the presence of colored makeup.

Keywords: lighting, color, design, Fechner's colors, PIFCs

Introduction

Color perception has long fascinated scientists, artists, and designers. While the physical properties of light and e.m. waves can be objectively measured, the color itself is subjective, experienced solely within the human mind. German psychologist Gustav Theodor Fechner discovered the Fechner's color effect in the 19th century (Fechner, 1860). Due to a perceptual phenomenon connected to how our visual system interprets black-and-white patterns, people can perceive Fechner's colors.

Fechner's colors are perceived by the human visual system (HVS) as a result of intricate interactions, even though they are not truly present in the radiometric stimuli. Although the precise neural mechanisms underlying this phenomenon are not entirely known, it is believed to be caused by the activation of the blue-yellow opponent color channel, which causes the subjective perception of faint, complementary hues in response to particular patterns. Fechner's colors essentially serve as an example of how the human mind creates a psycho-perceptual experience called color perception in response to particular visual stimuli.

The primary objective of the designed tool is to deepen the color and lighting novice designer's understanding of color as a subjective sensation. By experimenting with Fechner's Colors, we aim to demonstrate that color is not an inherent property of objects or light but an interpretation generated by the HVS. The tools seek to uncover the mechanisms underlying Fechner's Colors and their implications for color perception. We can see that Fechner's Colors are not physically present in the stimuli but arise from the complex interaction between the visual system and the black-and-white flashing patterns. Participants consistently report perceiving faint, flickering hues not present in the stimuli.

The designed tool demonstrates to subjects that color is a psycho-perceptive sensation generated by the human mind. Fechner's Colors provides compelling evidence that color perception is an interpretive process influenced by the interplay of visual stimuli and the neural mechanisms responsible for color-processing opponent color channels. Novice lighting and color designers can draw from these findings to develop a deeper understanding of the subjective nature of color, allowing them to employ colors more effectively in their creative endeavors.

Fechner's colors effect

It was reported that Gustav Theodor Fechner discovered the color effect that bears his name by pure chance (Bagley, 1902) while trying to create various shades of gray using a rotating disc with black and white stimuli. The best-known example of Fechner's chromatic effect was proposed at the end of the nineteenth century by the toymaker (Benham, 1894) with a disc also called Benham's top (fig 1). In his spinning top, subjects will be presented with high-contrast black-and-white rotating patterns, and they will be instructed to observe and report any subtle colors they perceive.

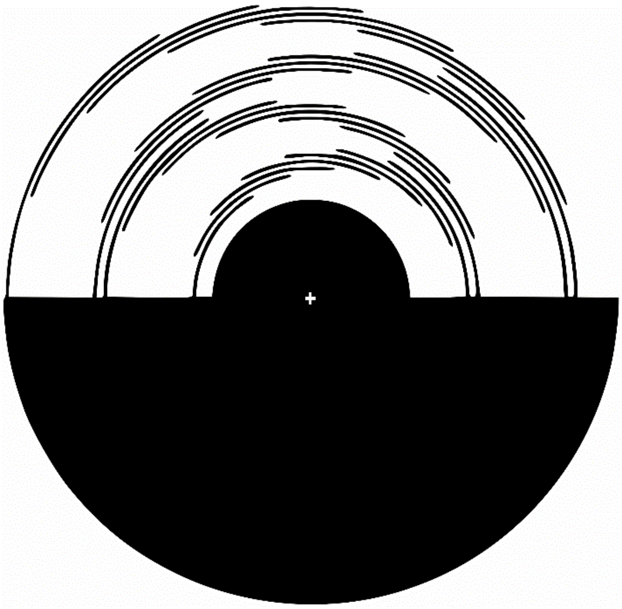

Fig. 1 – An example of the Benham's disk.

This visual effect falls within the more general definition of pattern-induced flicker colors (PIFCs) defined by (von Campenhausen *et al.*, 1992). Although the HVS mechanisms underlying PIFCs are still unclear, some researchers thought this effect to be primarily on the retina rather than the cerebral cortex processes.

It is hypothesized that one of the causes of the PIFCs effect is due to the slowness of the blue cones compared to the yellow-green and red ones of the retina in receiving flickering stimuli at specific frequencies, and this has effects on the blue-yellow opponent color channel which loses a part of the blue stimulus (Schramme, 1992; Le Rohellec and Viénot, 2001). PIFCs should involve the retinal ganglion cells (RGC) of the blue-yellow opponent system (Schramme, 1992), the amacrine cells, and the center-surround receptive fields due to lateral inhibition systems (von Campenhausen *et al.*, 1992; Kenyon *et al.*, 2004).

However, more recently, (Tanabe *et al.*, 2011) have also investigated the effects on the visual cerebral cortex. Using rapid functional magnetic resonance imaging (fMRI), they observed differences between real colors and PIFCs in the modulation between the cerebral cortex from V4 to V2 to V1, deducing that the connection between V4 and V1 would also come into play in the perception of the PIFCs. The implication of higher brain levels in the vision of PIFCs has also been hypothesized by (Le Rohellec and Viénot, 2001).

For PIFCs to be visible, the frequency of alternation of black and white stimuli must be much lower than the critical flicker fusion (CFF) (de Lange, 1958) of the HVS. It has been observed that visible PIFCs are always flickering and desaturated (Jarvis, 1977). More significant chromatic effects are obtained with frequencies of approximately six rotations per second and not less than three rotations per second (Brown, 1965). Most experiments were carried out using Benham's circle, but PIFCs can also be observed with other non-rotating systems capable of generating alternating light and dark flickering (Gerjuoy and Clarke, 1958; Müller *et al.*, 1980; Krantz, J. H, 1999) or by moving the view on fixed black and white images (Chudler, 1996; Burridge, 2018).

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The designed tool

It may seem strange, but most people, even graduates, do not have a clear concept that color is a psychophysical process. This experiment does not intend to demonstrate anything new. It is mainly aimed at explaining to color and lighting novice designers that color is not an inherent property of objects or light but an interpretation generated by the HSV through direct observation of the phenomenon rather than seeing it on a screen. This also prevents anyone from thinking there might be a trick on the screen representation.

We carried out the experiment in a confined space on a reduced scale, allowing subjects to verify the effects visually. The project involves a black cubic-shaped box with 30 cm sides. The tool is completed with an information card explaining this optical illusion's known scientific basis. Under the box, there are two rails that house a sliding card explaining the experiment. The card is bound to the box (Fig. 2).

Fig. 2 – The black box design with the rails and the bounded info card.

The experiment is housed in a black box to control the lighting conditions with a diffusing white LED lighting system with 4000K CCT inside the box. The Benham's disc is observable through a hole in the box under controlled lighting conditions (Fig. 3a). For ease of transport and safety, the power cable for the electricity supply is rolled up and placed in a special compartment at the back of the box (Fig. 3b).

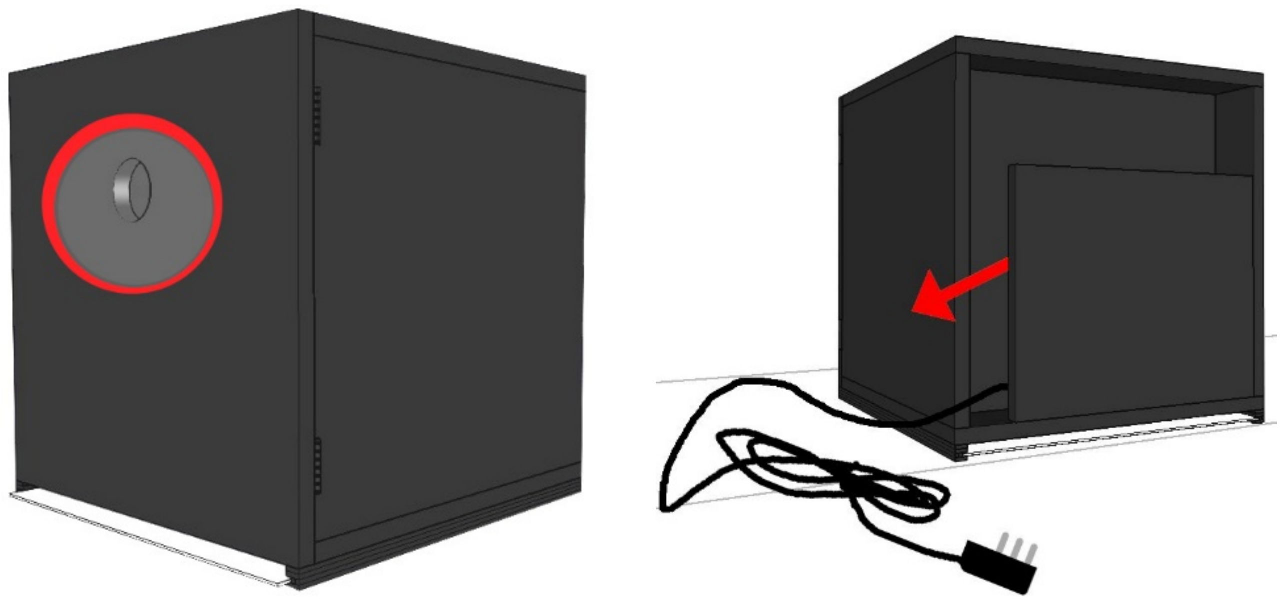

Fig. 3 – (a) The hole to see the experiments, and (b) the back of the box with the power cable.

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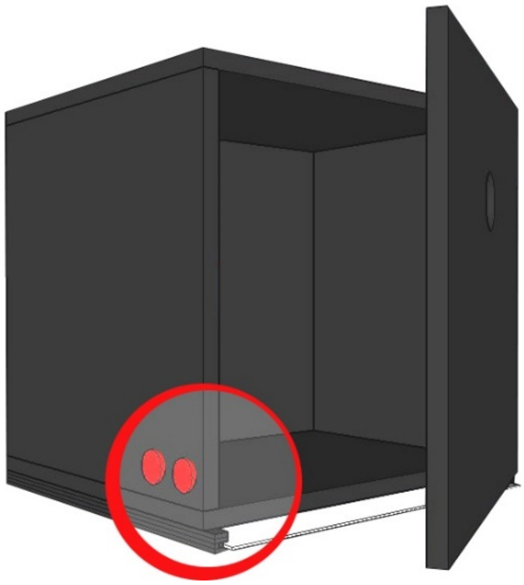

Fig. 4 – The two power switches, and the front door is attached with two hinges.

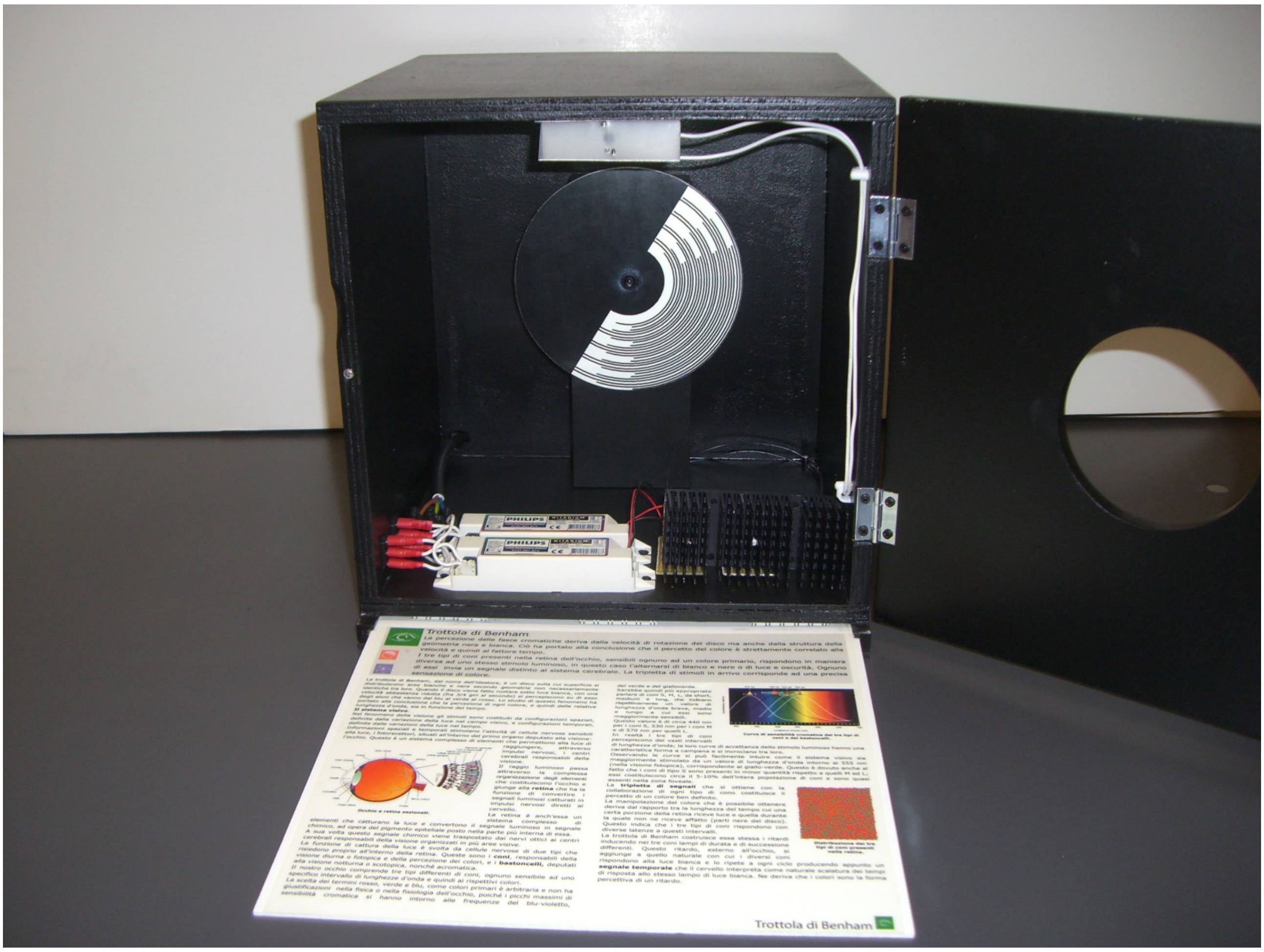

Fig. 5 – The manufactured experiments opened.

Two switches are provided that allow subjects to turn on the internal LED light and start the electric motor that rotates the Benham's disc (Fig. 4). The rotation speed is fixed and has been experimentally verified to have the most significant color effect to 6 rotation per second (Brown, 1965). The box can be opened to let in ambient light, and subjects can also see the experiment under different lighting conditions, switching off the internal LED light source. The experiment was designed to allow the box to be manufactured quite simply (Fig. 5) and to be easily used by involved subjects to see Fechner's colors effect (Fig. 6).

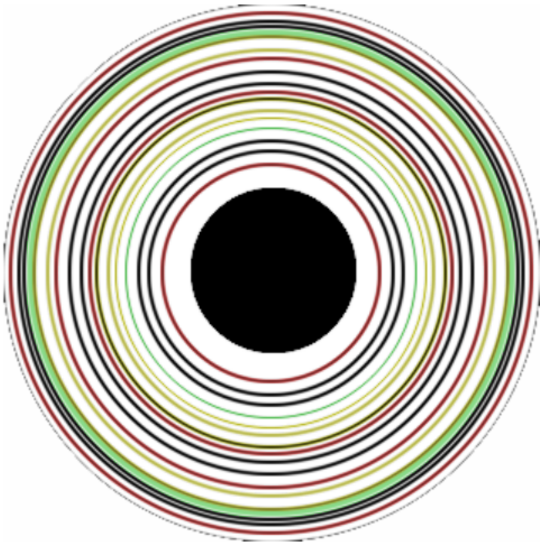

Fig. 6 – A representation of the possible Fechner's colors visible to the subject trying the experiment.

Conclusions

The primary HVS perceptive elements that are involved in color and lighting design are light sources, materials, physical environments, and people. The physiology and psychology of visual perception cannot be split up from the radiometric physical-phenomenological reality of light radiation. This premise is supported by the observation that the HSV interprets the environment rather than recording it, which was first made experientially by Josef Albers (Albers and Weber, 2006) but was later confirmed by science (Land, 1977).
We can also think of the presented experiment as an application to color and lighting design of the experiential methodological principles created in the Bauhaus basic design. The development of Gestalt psychology, which developed in Germany at the beginning of the 20^{th} century, significantly impacted basic design, connecting perception with phenomenological experience (Koffka, 1935). According to (Kanizsa, 1997), the experiment's goal is to establish cause-and-effect links rather than to demonstrate some weird phenomenon, and he emphasizes the importance of the method and the purpose of experimental phenomenology. This is the crucial point for the design practice. The classic experiential phenomenology method is applied to make subjects understand the importance of the psycho-perceptive aspects of colors.
In conclusion, this experiment utilizing Fechner's Colors underscores the psycho-perceptive nature of color, demonstrating that it exists within the human mind. Novice designers can benefit from this understanding, enhancing their ability to manipulate and employ color and light in their work effectively. By appreciating the subjective nature of color, designers can unlock new avenues of creativity and create visually engaging experiences.

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From color design to CMF design – a curriculum of a color course for design students at the Academy of Fine Arts in Krakow

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Abstract

The purpose of this paper is to compare the color design curricula at the Jan Matejko Academy of Fine Arts in Krakow, starting from the establishment of the Faculty of Industrial Design in 1964 to the present. The Krakow school of design is a unique place in Poland, where the amount of time reserved for color issues allows students to both learn the fundamentals of light and color theory and complete several assignments and projects. The Space and Color Studio is one of the so-called directional studios, having an elective character, in which the number of classroom hours amounts to 240 during the academic year. This allows students to pursue color topics in product design, working environments, interiors with different functions, architecture and visual communication. In addition to elective classes, the design program has always included a compulsory fundamental course of 120 hours, taught in the second year of undergraduate studies, first in the Visual Fundamentals of Design Studio and then in the Color Knowledge Studio. Starting in 2018, CMF topics were introduced as part of this course and the creation of a CMF library for design students began. In the almost sixty years of the Department's existence, the topics of color have been significantly related to economic, social and even political contexts. Due to the volume of this article, only selected issues will be cited and the authors intend to compare both the range of topics and the teaching methods used.

Keywords: color education, color design, CMF design

Introduction

The Faculty of Industrial Design was established at the Academy of Fine Arts in Cracow in 1964. Since it was the first school of its kind in Poland, the goal of the founders was to create a model program for design education. The studies lasted six years, with the last year dedicated to the master's degree project. Initially, the number of students in one year was 10. The four chairs were established: the First Chair of Sculpture, Painting and Drawing, the Second Chair of Developing Production Equipment, the Third Chair of Product and Visual Communication Development and the Fourth Chair of Industrial Color Design (Dziedzic and Starzyńska, 2014). Antoni Haska, a painter by background, became the head of the Fourth Chair. Since the theory and practice of color in art were close to his heart, he wanted to apply these experiences to the field of design.

The Chair of Industrial Color Design (1964-1992)

Because there were no design schools in Poland before 1964, design work was undertaken by engineers, architects or artists. Since the choice of color is, in popular perception, a task requiring artistic competence, topics concerning product color or interior color were among those that most often went to artists. There was a lack of professional reference literature and the primary source of color knowledge was the comprehensive monograph 'Color Science' by Adam Zausznica (Zausznica, 1959). No sample books or color atlases were available and all color swatches and exercises were done by hand. In the Chair of Industrial Color Design, it was necessary to create a program in which color was subordinated to utilitarian requirements and aesthetic concerns were not foregrounded. 'Shaping the Visual Imagination' is the text in which Antoni Haska presented a program of training in the Chair of Industrial Color Design (Suszczyńska-Rąpalska 1999). The goal was to educate a designer rather than an artist, so inspiration came not only from the field of art, but also from science: physics, mathematics, biology, psychology, and sociology. Important was the ability to observe, reproduce and transform color arrangements (Fig. 1)

Fig. 1– Color model (mapping) and its interpretation on a modular grid (picture glued together from individual squares)

Design topics included the color schemes for workplaces, production halls and various types of industrial machinery and equipment. The Pittsburgh Paints Color Dynamics Scheme and the Guidelines of the British Colour Council (Zausznica, 1959) were used in the design of industrial interiors. Typical color schemes for machinery for processing various types of materials were used, and recommendations for the contrast between machine and background were applied (Fig. 2). The students carried out several projects designed for various types of industrial plants, including furniture factories, galvanizing plant hall, thermal power plant interiors, cosmetics factory, maintenance workshops and others. The projects were presented in the form of mock-ups and models along with a set of color samples. The design tasks were accompanied by theoretical classes, conducted by specialists from the Faculty of Psychology and the Faculty of Physics of the Jagiellonian University.

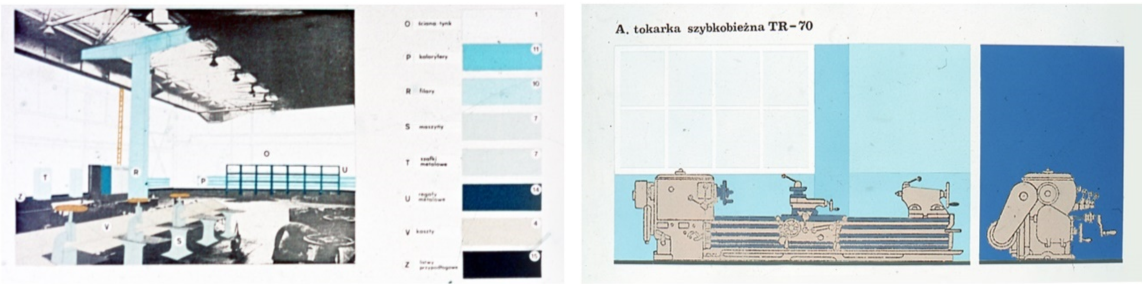

Fig. 2 – Color design of the workplace at the lathe and milling machine.

In communist Poland, companies were owned by the state, so the marketing context of the color design was virtually nonexistent. There were constant shortages of basic products and customers bought whatever appeared in the stores. At the same time, teaching was aimed at solving social problems and phenomena such as the influence of color on commercial success were considered a topic that designers should not concern themselves with (Pawlowski, 1980). In product color design, the emphasis was on the color-form-technology relationship, and criteria related to brand identity or color trends did not appear (Fig. 3)

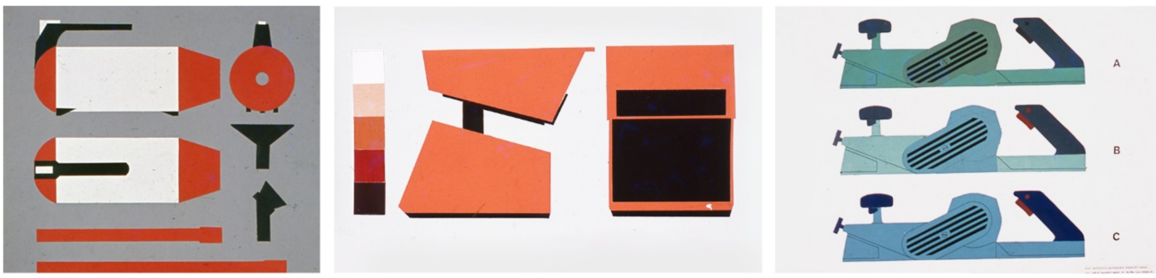

Fig. 3 – Color designs for a vacuum cleaner, kitchen scale and planer.

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Color palettes for the building industry

The 1970s in communist Poland was a time of prefabricated housing. After 10 years of experimentation, Polish engineers developed their technology for building prefabricated houses – under the name W-70 (Chomątowska, 2022). Polish standards defined the maximum number of square meters per inhabitant, the apartments were labelled M-1, M-2, M-3, M-4, M-5, with the figure denoting the number of inhabitants. There were 160 "house factories" – ready-made walls with windows and facades. Since the construction companies, like all others, were state-owned, top-down plans were developed both in terms of the organization of space and regarding the color scheme of the facades and interiors. The team of the Industrial Color Department carried out, commissioned by the Institute of Industrial Design, a series of projects called 'Studies on the color space of housing estates and residential interiors' – 1977, 1978, 1980 (Fig. 4). The students' topics concerned the use of ceramic and glass mosaics for large-scale housing developments (Dziedzic, Starzyńska, 2014). They studied changes in color impression from different distances and in different lighting, as well as the effect of spatial color mixing.

Fig. 4 – Color system and subsystems – residential housing estates

Color palettes for typical residential interiors were created (Fig. 5). A color scheme characteristics chart was developed, which became a tool to describe color compositions used in apartment designs. The interior color schemes were dedicated to apartments of different sizes and the proposed colors and materials took into account the specifics of the Polish market. The presentation of colors in a circular diagram allowed both the evaluation of various types of contrasts and quantitative proportions.

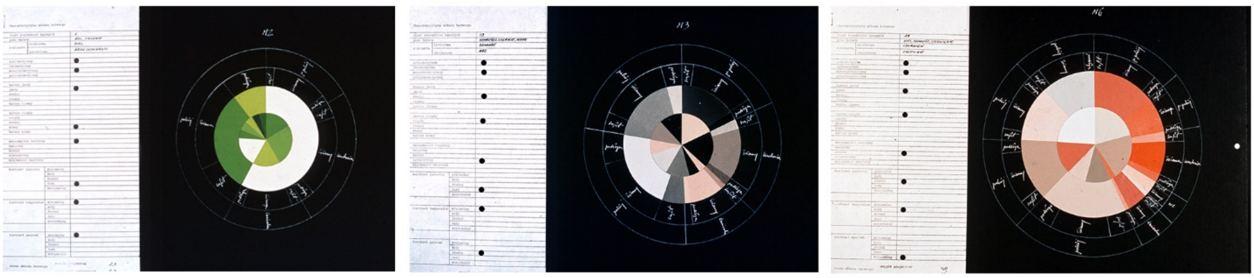

Fig. 5 – Color design of M-2, M-3 and M-6 apartments

An important topic was complex color design for facilities such as schools, kindergartens, and health care facilities. Such tasks were often carried out as graduation projects, among them were the design of a color system for the interiors of the Children's Rehabilitation Sanatorium in Radziszów or a comprehensive color concept for the Pulmonology Clinic in Cracow. Projects of this type required both direct cooperation with the institution and specialized consultation.

The Chair of Space and Color (1992 -)

In 1992, the name of the Chair was changed from the Chair of Industrial Color Design to the Chair of Space and Color and Barbara Suszczynska-Rąpalska became its head. The thematic scope was maintained, focused on interior and architectural color design. However, the types of buildings and

interiors dealt with changed significantly. This was related to the changes in Poland after the political transformation in 1989, when privatized hotels, cinemas, cafes and restaurants began to operate intensively and state-owned industrial plants ceased to be the main client for designers. The construction of prefabricated homes ceased in 1989 and the topics of color in architecture included issues of revaluation of tenement houses, which, due to the high level of air pollution in Krakow (acid rain), had been heavily degraded for many years.
The manner in which the projects were carried out was more aimed at developing the students' color sensitivity than at creating solutions that could be applied in practice. Projects were carried out for a number of architectural complexes in the center of Krakow, including the color scheme for Aleja Trzech Wieszczów, Rynek Podgórski, Floriańska Street, and Central Square in Nowa Huta.

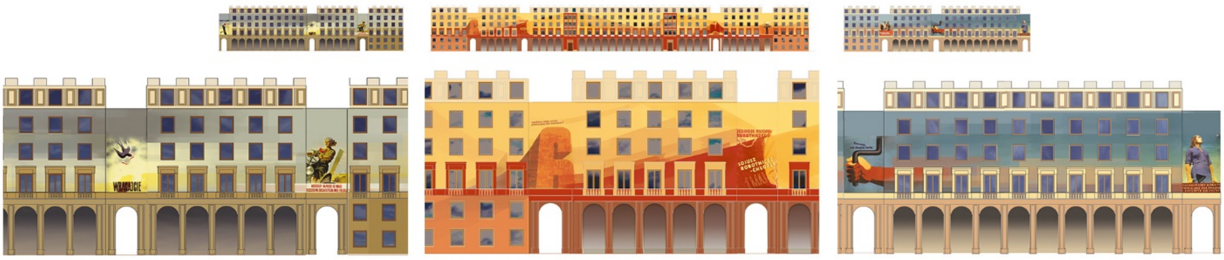

Fig. 6 – Color design for Central Square in Nowa Huta, student J. Smolnicki

The color design of the Central Square in Nowa Huta (Fig. 6) was a search for the visual identity of the working-class quarter, which was created after World War II as a kind of counterbalance to the academic city of Krakow that was reluctant to the new communist government. Nowa Huta was conceived in the 1950s as a project for an entirely new city, along the lines of the international modernist movement. The goal of the assignment was to look for a color palette that would highlight the history of the place and contribute to its revitalization.
Interior color assignments were aimed at creating solutions with high aesthetic qualities, less attention was paid to the functional program. An example is the diploma work of D. Motyka and W. Motyka focused on the interiors of the Helena Modrzejewska Old Theater in Krakow.

Fig. 7 – Color design of the Old Theater in Krakow, student D. Motyka, W. Motyka

The Studio of Color Knowledge (2004-)
From the very beginning, the Chair of Space and Color included a studio dealing with the fundamentals of color design. In the 1990s, it was the Visual Fundamentals of Design Studio. In 2004, it changed into the Studio of Color Knowledge and Agata Kwiatkowska-Lubanska became its head. The studio runs a course, mandatory for all undergraduate students. The number of hours is 120 per year. Topics covered in the course include features of color, visual phenomena related to color, subtractive and additive mixing, color measurement and recording, CMYK, RGB, Pantone, RAL, NCS systems, issues of color printing and color management in visual communication and product design. Students are introduced to the psychological impact of colors, ways to communicate through color and theories on color harmony. The NCS system is a tool used in understanding color perception (Fig. 8)

Fig. 8 – Color analysis using the NCS tools; students W. Skawski, M. Madej, M. Komar

At the beginning of the course, students do a series of exercises by hand with various types of paint, creating color samples used for further assignments. This is a very important part of the program, as it helps students develop color sensitivity and an awareness of the relationship between color and material. The results of working with paint allow students to understand the principles of mixing piments, reproduction of different colors and also the formulating of colors in the industry, among others.

Figure 9 presents an exercise aimed at creating a color palette obtained from mixing 3 selected colors and white, except that these could not be primary colors. Creating color palettes dedicated to different types of materials is a task that aims to highlight the color-material-surface relationship.

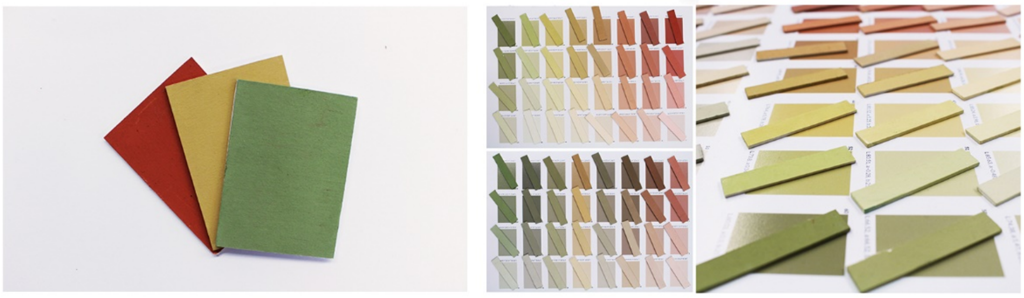

Fig. 9 – Design of a color palette obtained from mixing 3 colors, student M. Baran

Another series of exercises are tasks devoted to CMYK mixing. Since many students choose to specialize in visual communication, understanding the principles of subtractive mixing in print and the range of colors possible in this way is very important for them. Therefore, a mandatory task in the winter semester is to create a color palette based on CMYK colors. Students also design their color atlases and then print them (Fig.10). It is related to issues of color management in graphic programs, photo processing and working with print shop.

Fig. 10 – Design of a color atlas, student T. Twardowski

As a natural continuation of these issues, color projects are assigned for tasks in visual communication: comprehensive brand identification, colors for packaging, visual information systems and other forms of communication through color. In the assignment, which aimed to prepare a comprehensive visual identity for a nonprofit association selected by the student (Fig. 11).

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The project included a color scheme for the logo, basic printed matter, website and exterior signage. The students worked under the direction of Agata Kwiatkowska-Lubanska, Marta Osipczuk (color design) and Peter Javorik and Natalia Pietruszewska-Golda (graphic design). Research was conducted on the semantics of colors using Ch. E. Oswood's semantic differential method (Ploder and Eder, 2005)

Fig. 11 – Color identification design for selected association, student N. Michańków, B. Kwaśnica

The CMF Lab

The dynamic growth of material libraries in the 21st century, along with the development of manufacturing technologies and materials, allows designers around the world to be inspired, first and foremost, to seek alternatives to overconsumption and environmental degradation. Faced with these opportunities, the designer's decisions regarding not only the choice of material but also color and surface finish have become an extremely important part of the design process. Many authors (Becerra 2016, Zuo 2018, Zhang 2020) have begun to write about a new field of design called CMF Design. Several universities around the world already offer paid courses and postgraduate programs for CMF designers.

Marta Osipczuk, who was employed at the Color Knowledge Studio in 2017, chose the issues of preparing a new CMF design education program as the topic of her doctoral dissertation. Since 2018, the CMF Laboratory has begun to be established, based on materials accumulated in the department and obtained by the doctoral student from Polish and foreign manufacturers (Fig. 12). The materials collected in the Lab have been used in many student assignments and exercises in product, interior and transportation design – Colour&Trim (Fig. 13)

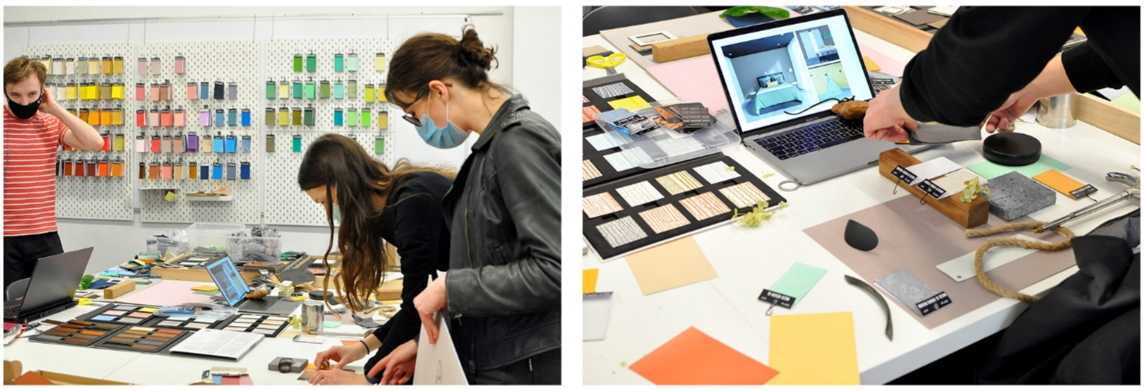

Fig. 12 – Students in the process of creating material boards for interiors using the emerging CMF library.

The CMF-based design methodology incorporates such elements into the design process as creating a CMF strategy for manufacturers based on the brand's philosophy, its technological capabilities, market analysis, and prospects for innovation, among others. Students learn how to create and use inspiration boards and material boards in the initial design phase, create detailed CMF documentation for individual elements, and analyze the feasibility of using biodegradable or recycled materials in the design, which requires a high level of sophistication.

Fig. 13 – CMF design of the interior and exterior of a train for Małopolska Railways, carried out in cooperation with Newag, a Polish manufacturer of train sets, student M. Kocot

Crucial to the implementation of CMF design topics is undertaking cooperation with Polish manufacturers. The teachers make an effort to ensure that each year students can create concepts embedded in market realities. An example is the design of a limited edition car seat for the Polish brand Avionaut. Students were given a selected model of car seat, for which they had to develop CMF of upholstered elements taking into account technological conditions, functionality, trends and approvals of selected materials (Fig. 14)

Fig. 14 – Design of a limited series of infant car seat, cooperation with Polish manufacturer Avionaut, student M. Baran

Another example is the designs of the mentioned color and material palettes for residential interiors (Fig. 15), which are created from samples available in the studio and samples and artifacts found by students. Students create CMF boards for individual rooms, experimenting with different kinds of color and material combinations, and then create a visualization from scratch or in a mockup provided by the instructors.

Fig. 15 – CMF project of an apartment, student A. Bartyzel

The growing CMF fundamentals course is a response to current and upcoming requirements about the job market for both industrial designers and the growing demand for designers specializing in CMF design.

Conclusions

An analysis of the didactic program in color design at the Faculty of Industrial Design of the Jan Matejko Academy of Fine Arts in Krakow allows us to formulate a thesis that regardless of external or internal changes – this field of design is very important at the Krakow Academy and many people contributed to the development of the didactic program, some of whom, such as Professor Antoni Haska, was extremely respected in Polish art and design. In this context, the school is a favourable exception to many universities, where, according to researchers who analyze the subject (Calvo Ivanovic, 2023), the number of hours devoted to color in the curricula of designer education is far too small. Teaching is carried out in two ways: as a mandatory course, providing basic knowledge and skills, and in the form of advanced design assignments. The variability in the scope of the subject matter is due both to the development of the color science and the increased availability of literature and various design tools over the past 60 years, and to the different external contexts, related to political, and economic changes in recent Polish history.

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10. Colour Photography and Film

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Towards the identification of original dyes in chromogenic films: the development of an approach based on chemical analyses

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Abstract

Four colour movie films of different brands and with different polymeric support, dated from 1990 to 2006, were studied from the point of view of the chemical structure of the chromogenic dyes. Both spectroscopic (Raman and surface-enhanced Raman) and chromatographic (thin-layer chromatography and high-performance liquid chromatography-mass spectrometry) techniques were used, and it was possible to establish a comparison between the dyes in the different films, together with a tentative attribution to couplers of different molecular classes.

Keywords: chromogenic films; dyes; chemical analyses.

Introduction

The main problem that conservators have to face with regard to the latest generation of cinematographic films, chromogenic films, is the fading of colours, the only solution for which is represented by digital restoration. In fact, the original dyes cannot be chemically restored, but their knowledge can nevertheless be significant for this process. In chromogenic films, colour is produced through the so-called subtractive synthesis, based on the combination of cyan, magenta and yellow dyes. These substances are formed during the development process following the reaction between the couplers, which are divided into the three different layers of the emulsion, and the oxidized developer. The chemical nature of these compounds, whose molecules are extremely complex, is not disclosed by the manufacturers, thus posing a difficult challenge for their identification by chemical methods of instrumental analysis.

Only a few examples have already been reported in the literature for the characterization of chromogenic dyes, based on the use of surface-enhanced Raman spectroscopy (Longoni *et al.*, 2022), Raman and Fourier-transform infrared (FTIR) spectroscopy (Di Pietro, 2007; Silva *et al.*, 2022) and high-performance liquid chromatography – mass spectrometry (HPLC-MS) (Silva *et al.*, 2022). In all cases however one or the other of the above techniques was applied to a limited choice of film samples, and only two of the reported papers refer strictly to movie films (Di Pietro, 2007; Longoni *et al.*, 2022).

In the present work, four portions of chromogenic 35-mm positive films of different brands were studied by vibrational spectroscopic and chromatographic techniques, aiming at the characterization of the corresponding dyes. In detail, the materials examined were: three Eastman Kodak films, two dated back respectively to 1990 and 1993, for which no code was available and a 2383 film (the date of the movie was not available, but the film was produced from 1999 to 2003); and a Fujicolor Eterna cp 3513D film (2006) (preliminary studied in Longoni *et al.* 2022).

Methods

The polymeric supports of the films were identified by attenuated total reflectance (ATR) FTIR spectroscopy, using a a Jasco FTIR–470 spectrometer, and a zinc selenide ATR single reflection crystal with 45° angle of incidence. Each spectrum was obtained with resolution 4 cm^{-1}, as the sum of 256 accumulations in the range 4000-700 cm^{-1}. All films were analysed non invasively by simply putting a part of them in strict contact with the crystal.

For the analysis of the dyes, samples of the emulsion were taken from black lateral areas of the films with the aid of a scalpel under a stereomicroscope. For the chromatographic separations of the dyes, the emulsion was used as a whole after extraction with ethanol:water (3:1), while for the Raman analysis the layers corresponding to the different colors were selectively scraped and a further selection was made with the aid of a needle, always under the microscope.

Raman measurements were performed by a Bruker BRAVO handheld spectrometer, using two excitation wavelengths (850 nm from 300 to 2000 cm^{-1} and 785 nm from 2000 to 3200 cm^{-1}) and resolution around 11 cm^{-1}. The acquisition time ranged from 500 ms to 2 s and the number of accumulations from 5 to 300.

Details about the thin-layer chromatography (TLC) separation of the dyes and the surface-enhanced Raman analysis are reported in (Longoni *et al.*, 2022). Briefly, a suspension of silver nanostars was used as SERS-active substrate and the spectra were acquired with a 532-nm excitation wavelength using a a JASCO RMP 100 portable Raman micro-probe.

HPLC-MS analyses were performed using a Thermo Fisher LCQ Fleet ion trap mass spectrometer equipped with the UltiMate™ 3000 UPLC system with ESI source and UV detector (λ 546, 650 and 438 nm) and a C18 column (3.5 µm, 4.6 x 150 mm). The eluents were (A) H_2O milliQ + 0.01% HCOOH and (B) MeOH and the following gradient was used: 0'-2', 70% A - 30% B; 20'- 33', 100% B; 35'- 45', 70% A - 30% B.

Results and discussion

Based on ATR-FTIR spectra (Fig. 1), for the two older Eastman Kodak films the support was recognized as cellulose acetate (Nunes *et al.*, 2020), while for the Kodak 2383 film and the Fujicolor film polyethylene terephthalate (PET) was identified as expected (Pereira dos Santos *et al.*, 2017).

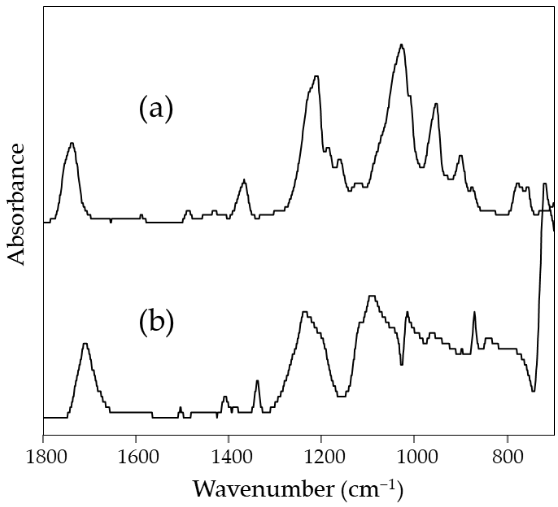

Fig. 1 – Examples of the ATR-FTIR spectra obtained on the polymer side of the films examined: (a) Eastman Kodak 1990; (b) Fujicolor 2006.

As regards the dyes, for the magenta colour in all four films the same dye formed from a coupler belonging to the family of pyrazolones could be detected, based on the Raman and SERS spectra (Fig. 2) (Longoni *et al.*, 2022) and on the HPLC-MS data (same retention time and m/z value). For the cyan colour, Raman and HPLC-MS analyses indicated that three different dyes were used, two for the older cellulose acetate films and the third for the two more recent PET films, but the SERS spectra indicated, at least for the Eastman Kodak 1993 film, that they derived from couplers belonging to the same molecular class of naphthols (Longoni *et al.*, 2022). As concerns the yellow colour, HPLC-MS data could be acquired just for the two PET Kodak and Fujicolor films, demonstrating the presence of a common dye, with the addition of a second one only in the Kodak film. Probably due to the low concentration of the dye, no SERS signals could be acquired for the films with the exception of the spectrum already reported for the Fujicolor one, but Raman spectra resulted quite similar for the two PET films and for the Kodak Eastman film dated to 1993, again suggesting that a coupler belonging to the family of benzoyl acetanilides was used in all cases.

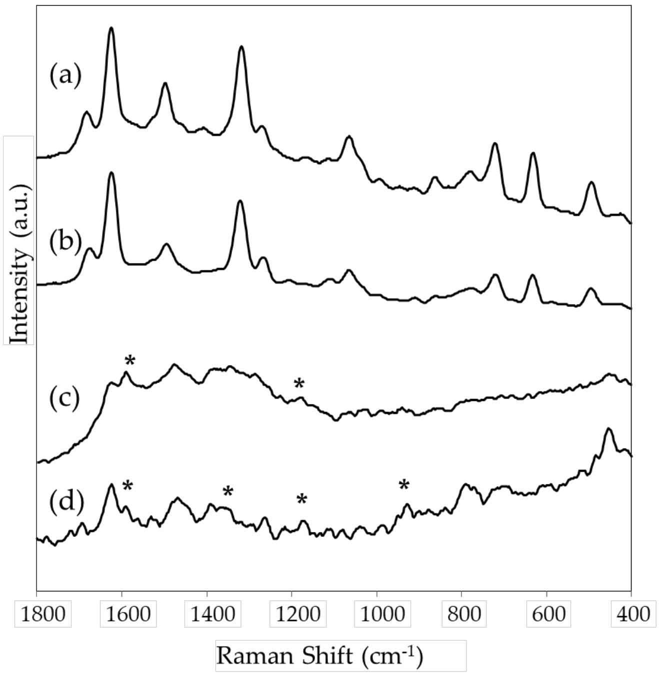

Fig. 2 – Examples of the SERS spectra (λ_{exc} 532 nm) obtained on the dyes extracted from the emulsion of the films examined: (a) magenta dye from Eastman Kodak 1993; (b) magenta dye from Fujicolor 2006; (c) cyan dye from Eastman Kodak 1993; (d) cyan dye from Fujicolor 2006. Legend: * = spurious bands due to the silver colloid.

Conclusions

The present work represents an effort in the direction of the chemical investigation of chromogenic dyes in movie films. Even if, similarly to previously reported papers, a univocal identification of the dyes has not been obtained, an assignment to molecular classes could be hypothesized. Moreover, this is a first attempt to build a database of spectroscopic and chromatographic data on these dyes. Looking ahead, this database, if sufficiently expanded, could be useful for comparing different films, especially in those cases where detailed information about the film itself is lacking and therefore spectral density curves for the three colours are not available.

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Preliminary investigation into the use of spectrophotocolorimetry to quantify colour changes of passive samplers for the detection of acetic acid: an application to cellulose triacetate films affected by Vinegar Syndrome

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Abstract

Vinegar Syndrome (VS) is the main degradation phenomenon of cellulose acetate films, resulting in the release of acetic acid (AA) with a vinegar-like odour. This chemical process is spontaneous and autocatalytic, and it is extremely accelerated under certain thermo-hygrometric conditions. Currently, the most widely adopted strategy in film archives is the periodic inspection of AA emissions from cellulose acetate materials using passive sampling (e.g., Acid Detection Strips® by the Image Permanence Institute or Dancheck AD Strips® by Dancan). These colour-change passive samplers are usually placed *in situ* for short exposures to detect the presence and to roughly estimate gaseous acidic compounds. In this way, films affected by VS can be identified and possibly isolated from unaffected ones. This contribution presents a laboratory study aimed at objectively quantifying the AA released from VE-affected cellulose acetate films, detected through colour-change passive samplers. In detail, UV-visible spectrophotocolorimetry was used to measure the variation in colorimetric features of the passive samplers in the C.I.E. L*C*h Colour Space before and after exposure to different concentrations of AA in a controlled environment. The colour change in the passive samplers, expressed in terms of Δh, was associated with the known AA concentrations, and a fitting curve was derived. In this way, the final hue value of the passive sampler can be associated with the AA emission from the cellulose acetate film, tracking its deterioration stage. A preliminary survey was performed on 100 cellulose acetate films stored at the Cineteca Nazionale of the Centro Sperimentale di Cinematografia (CSC) in Rome. Most of them resulted in an optimal or good state of preservation, as only about 30% were above the autocatalytic range. The proposed approach could easily be applied to refine the screening of large collections based on the VS stages of films without losing the speed of screening. An improvement in the assignment of conservation priorities for VS-affected cellulose acetate films in relation to the occurrence of their release of AA would be achieved.

Keywords: Acetic Acid, Preventive Conservation, Cellulose Acetate Film, Vinegar Syndrome, Passive Sampler, Colour Change, Spectrophotocolorimetry.

Introduction

In 1948, cellulose triacetate was introduced as a support for professional motion-picture films, and it gradually replaced the previously widely employed flammable cellulose nitrate. In general, cellulose acetate films are polymers of the esters formed from cellulose and acetic acid (Bigourdan, 2000a). The degradation of cellulose ester film material is typified by the formation and release of acid up to the deposition of liquid/crystalline substances on the film surface. In the case of cellulose acetate films, the characteristic smell of acetic acid (AA) is the result of the deterioration process commonly known as *Vinegar Syndrome* (VS) (Allen *et al.*, 1988). Specifically, the cellulose acetate break-down consists of the hydrolytic deacetylation through the reaction of water with the bound acetyl group, resulting in hydroxyl substitution and AA release (Ahmad *et al.*, 2020). This chemical reaction has a long induction period, and it is non-linear with time: when triggered, it starts as a spontaneous and autocatalytic process, strongly accelerated under unfavourable environmental conditions (i.e., high temperature, high relative humidity, and/or low pH may cause film loss in few years) (Allen *et al.*, 1987). In addition, its triggering also depends on other co-factors acting synergistically, meaning the long-term history of storage and use (e.g., chemicals added for preservation issues, inert or chemically reactive can materials) and the intrinsic features of the film (e.g., industrial chemical composition, treatments during development process, production stock, year of manufacture). In detail, VS affects the entire complex film stratigraphy, leading to a decrease in pH, along with the dimensional instability of the support (i.e., precipitous decrease in tensile properties until liquefaction into a solid mass), the stickiness and/or stripping of the superficial emulsion, and the deposition of plasticizers on the film surface in the form of crystals or liquid drops. The loss of plasticizers from the support causes film embrittlement and shrinkage, that may reach 10% in extreme cases (Kammer *et al.*, 2021). The high amount of free AA released from a VS-affected film may damage the can, contaminating the surrounding atmosphere and the neighbouring unaffected films (Reilly, 2002). This phenomenon is known as *cross-infection* (Curran *et al.*, 2014) and it is commonly observed where films in excellent conditions and films suffering serious VS are stored in the same space. Since most film archives face the risk posed by VS (Bigourdan and Reilly, 2000), and the rapid disruptive course of deterioration places a nearly impossible burden on film archivists (Adelstein *et al.*, 1995), preventive conservation strategies have become widespread, aimed at avoiding films' loss through rational planning of corrective actions to be undertaken (Bigourdan, 2000b). In this context, periodic and extensive surveys of storage conditions are recommended, but this is physically and economically unrealistic for very large collections. Therefore, it appears crucial to have an effective *early warning* tool capable of detecting the initial decay of individual films, so that those affected by VS can be easily isolated to safekeep the rest of collection from cross-infection. Among non-destructive field tests available to monitor the stability of cellulose acetate film collections, AA passive sampling in the form of pH-indicator paper strips, introduced in the 1990s by the American RIT Image Permanence Institute, Rochester Institute of Technology (IPI), represents the best choice. Indeed, pH is a sensitive marker of incipient degradation of the film base, since the determination of free acidity confidently reflects the chemical changes in the cellulose acetate polymer (splitting of the acetyl side groups of the ester chain). Acid-base indicator paper strips are deployed within cans for film storage, and their colour change is a function of the pH change due to the AA released by the VS-affected film. The most widely adopted AA passive samplers are Acid Detection (AD) Strips® devised and produced by IPI (IPI AD Strips) and Dancheck AD Strips® developed and commercialized by Dancan Cinema Services S.r.l., Denmark (Dancheck AD Strips). The pros of these instruments are short exposures (at least 24 hours, depending on storage temperature), almost reliable and real-time reading, relative cost-effective and user-friendly, while the cons are sensitivity to light, interference with other acidic compounds, and qualitative output only (i.e., VS stage is ranked by comparing the strip colour to a discrete colour scale provided by the manufacturer). To overcome the issues of purely qualitative performance and subjective interpretation in directly reading the AD strip colour, reflectance spectrophotocolorimetry has been employed (Hackney, 2016; Townsend, Hackney and Kearney, 2023). Colour measurements of AD strips appear to be promising, as they provide consistent and reproducible results in terms of correlation between the colour change of AD strip deployed within a film can and the pH measure performed near the AA-emitting film. Based on the outputs of previous literature on the topic, it appears pivotal to improve the use of this methodology in order to make it feasible for film curators, also comparing the performance of AD strips produced by different brands. To our knowledge, this issue has not been properly explored, therefore the aim of this contribution is to provide a new fitting curve (i.e., a correlation between the chromatic coordinates measured by spectrophotocolorimetry on an AD strip exposed to an acetate film, thus changed or unchanged in colour, and the respective concentration of AA within the film can), and a continuous colour reference practical for archivists to quantify the AA released from acetate films more or less affected by VS.

Materials and Methods

Colour-change acetic acid passive samplers

Acid Detection (AD) strips are colour-change AA passive samplers manufactured by imbibition of filter paper in a solution of bromocresol green (i.e., tetrabromo-m-cresol-sulfonphthalein, an atoxic acid-base dye soluble in water and alcohol) dissolved in denatured ethanol. When AD strips absorb gaseous AA, it dissociates and reacts with the alkaline sodium hydroxide (added in formulation to enhance the colour change). The change of pH causes ionized blue indicator to change progressively towards green (pH = 5.4) and yellow (pH = 3.8) un-ionized forms. Tables 1 and 2 refer to two commercialized AD strips, reporting acidity levels of IPI AD Strips® and pH values of Dancheck AD Strips®, respectively. The information is enriched by the related qualitative and discrete colour changes. A brief description of the state of preservation (odour, acidity, etc.) of cellulose acetate films at different stages of deterioration is also supplied. It should be noted that IPI provides a sort of correspondence between A-D Strips® acidity levels and relative AA amounts in the air. Finally, IPI assumes that the autocatalytic point of VS corresponds to a film emission of around 3000-5000 ppb.

Table 1 - Correspondence between IPI AD Strips® level, their colour change, and characteristic of cellulose acetate films.

IPI AD Strips® Level	Colour*	Film description	AA amount
0	Bright blue	Good, no deterioration or an acidity of 0 to 0.1	0 ppm
1	Blue-green	Degradation starting or an acidity of 0.2	1-2 ppm
1.5	Green	Point of rapid autocatalytic decay starting, acidity of 0.5	3-5 ppm
2	Green-yellow	Advanced deterioration or an acidity of about 1	6-8 ppm
3	Bright yellow	Critical state, acidity of 2 or greater, shrinkage and warping	> 18-20 ppm
* Strips fade if exposed to room light for several days. Strip paper is soaked with an indicator that runs if it gets wet.			

Table 2 - Correspondence between Dancheck AD Strips® pH, their colour change, IPI level and films' decay stages.

Dancheck® pH	Colour**	IPI Level	Film description
6-5	Blue	0	Fresh film (pH 6), decay is beginning/increasing (pH 5.5/5), no smell
4.8	Green	1	Degradation is more increasing with weak smell
4.6	Olive green	2	Autocatalytic Point with weak smell
<4.4	Yellow	3	Priority for film's duplication with strong smell
** If you leave the indicator in the open air, it will fade.			

Spectrophotocolorimetry

A Konica Minolta portable digital UV-vis spectrophotometer (model CM-2600d) was used to carry out colorimetric measures, in terms of reflectance spectra and C.I.E. L*a*b* and C.I.E. L*C*h colorimetric parameters, of both the brands of AD strips. This instrument is based on the physical measurement of reflected light through an integrating sphere (3 mm diameter aperture) in the visible range (wavelengths: 400 - 700 nm at 10 nm steps, standard deviation within 0.1%). Standard 10° observer, D65 light source, and UV energy at 100% were chosen; simultaneous measurements of SCI and SCE - specular component included and excluded - were performed, since for a matt surface such as AD strip the differences are small. The device was zero calibrated against a distant non-illuminated background and then calibrated on the white reflection disk provided by Konica Minolta. The spectrophotometer ensures a good inter-instrument agreement (ΔE* = ±0.2) and guarantees a measurement error on paper-based samples such as AD strips close to ±0.5 (Townsend, Hackney and Kearney, 2023) providing C.I.E. coordinates on both the L*a*b* and the L*C*h Colour Spaces (C.I.E., 2004). The colour changes of the AD strips were measured by comparing the colour before and after a 24-hour exposure to six AA concentrations (Table 3). For each AA concentration, 3 strips per brand were deployed on an inert ceramic plate within a glass dryer with gas-tight seals placed in a controlled environment (Climate Chamber: WEISS model WK1 1500) reproducing the typical climate conditions in real film archives (T = 15°C, RH = 45%). The colorimetric difference ΔE* was calculated as the Euclidean distance between points in the C.I.E. L*a*b* Colour Space (C.I.E., 2004).

From solution of glacial acetic acid to vapour acetic acid concentration above the solution

AA gaseous concentrations have been calculated according to Antoine Equation (Equation 1) by diluting glacial AA (17.5M) in MilliQ water and therefore deducing the gas-liquid phase equilibrium.

$$p_p = 1000 * e^{\left(A - \left(\frac{B}{(T(K))+C}\right)\right)} \text{ Eq. 1}$$

Where p_p (Pa) = partial pressure, the multiplying coefficient of 1000 is to convert from kPa to Pa, the dimensionless coefficients for AA: A = 15.0717, B = 3580.80, C = 224.650, T(K) = 273,15 + 15°C, universal gas constant R = 8,314 ((m^3*Pa)/(K*mol)), environmental pressure p = 101325 Pa, and known AA molar mass = 60,05, water molar mass = 18,02 from which to deduce number of moles, molar fraction, molar fraction of gas phase, mass per unit volume in gas phase, and converting from µg/m^3 to ppb (multiplying by 0.40). Six solutions, namely Solution A, B, C, D, E, F (i.e., abbreviated as S.A, S.B, S.C, S.D, S.E, S.F) were obtained, corresponding to different dilutions of glacial AA in MilliQ water. The solution molarity, the related gas phase concentration expressed in ppb and the order of magnitude (10^x), as well as the methodology to obtain the solutions are reported in Table 3.

Table 3 - Molarity, gas phase concentration and order of magnitude for the six solutions of acetic acid in water, the methodology to obtain the dilution of glacial acetic acid in MilliQ water is also reported for each of the six solutions.

Solution	Molarity	Gaseous concentration	10^x	Methodology
S.A	0.525M	53003 ppb	10^4	Diluting glacial AA 3 in 100 (3ml of glacial AA increased with MilliQ water in a 100ml volumetric flask)
S.B	0.175M	17723 ppb	10^4	Diluting glacial AA 1 in 100 (1ml of glacial AA increased with MilliQ water in a 100ml volumetric flask)
S.C	0.0525M	5275 ppb	10^3	Diluting S.A 1 in 10 (withdrawn 5ml of flask A, increased with MilliQ water in a 50ml volumetric flask)
S.D	0.0175M	1759 ppb	10^3	Diluting S.B 1 in 10 (withdrawn 5ml of flask B, increased with MilliQ water in a 50ml volumetric flask)
S.E	0.00525M	527 ppb	10^2	Diluting S.C 1 in 10 (withdrawn 5ml of flask C, increased with MilliQ water in a 50ml volumetric flask)
S.F	0.00175M	176 ppb	10^2	Diluting S.D 1 in 10 (withdrawn 5ml of flask D, increased with MilliQ water in a 50ml volumetric flask)

Application to the case study

In each of four chosen storage rooms of the Cineteca Nazionale of the CSC we selected and surveyed 25 cellulose acetate film cans with the following features: 35-mm films, different manufacturers, colour and black-and-white, positive and negative, produced from 1950 to 1991. A Dancheck AD strip® was deployed within each film can. The campaign consisted in both colorimetric and shrinkage measurements in relation to the original film dimension. To test the grade of film shrinkage a KEM Shrinkage Control Unit was employed. This instrument, once calibrated by the manufacturer (KEM StudioTechnik, Norderstedt, Germany), provides a direct reading of the film shrinkage percentage value with an accuracy of ±0.02 percent (measuring length = 10.5 film frames = 199.5 mm, measuring force < 0.5 N, measuring area max. = 3.5%, double operation mode for both 16mm and 35mm films).

Results and Discussion

Figure 1 shows the outcomes of the measured colours of both IPI AD Strips® and Dancheck AD Strips® after they have been exposed to the six AA solutions separately, hence exposed to the six AA concentrations in the air separately. Related reflectance spectra are shown in Figure 2, respectively for IPI AD Strips® and Dancheck AD Strips®. The higher AA concentration in the air, the more AD strip's colour tends to change from blue to yellow. Starting from the spectrophotometer output for each measure (i.e., in terms of L*, a*, and b*), we converted it in the additive Red-Green-Blue (RGB) colour model, knowing the D65 illuminant and the 10° observer. It is interesting to compare the obtained colour scale with the blue target (not exposed strip) and with the saturated passive sampler (strip exposed for long time to the emissions of AA from a cellulose acetate film in advanced VS, almost liquefied). There is a difference in objective and visual perception of the colour change in response to the same AA concentration for the two brands of AA passive samplers, confirming that Danchek AD Strips® develop a similar, but still visible lower colour change than IPI AD Strips® (Townsend, Hackney and Kearney, 2023). Since only a ΔE* higher than 3 can be discernible to the naked eye, an AA concentration higher than 5275 ppb (ΔE* = 22.6 for S.C) may be perceived with Dancheck AD Strips® (which colour change shows ΔE* = 1.3 for S.F, ΔE* = 2.5 for S.E, and ΔE* = 2.6 for S.D), while IPI AD Strips® allows to recognize the colour change more easily if the AA concentration is higher than 1759 ppb (ΔE* = 26.4 for S.D) and less easily if higher than 527 ppb (ΔE* = 15.8 for S.E), or higher than 176 ppb (ΔE* = 3.9 for S.F), confirming (Zappi *et al.*, 2022).

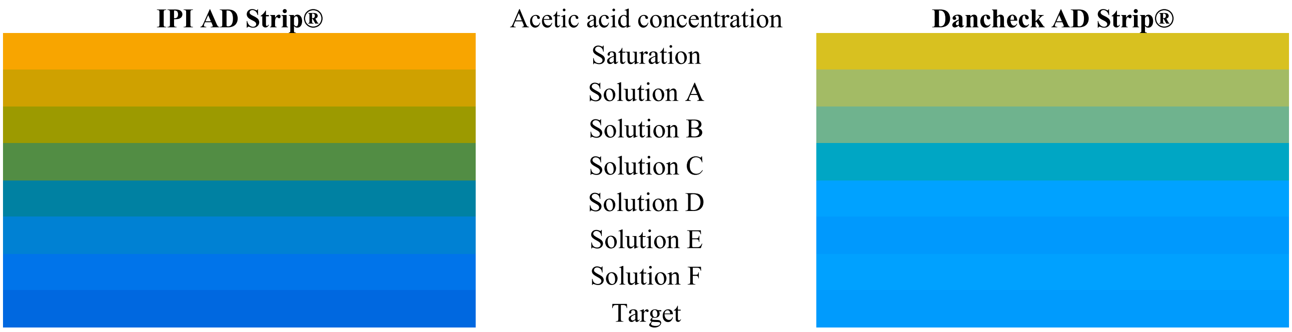

Fig. 1 - IPI AD Strips® (left) and Dancheck AD Strips® (right) colour changes from target (blue) to saturation (yellow) after a 24-hour exposure to six solutions (S.A, S.B, S.C, S.D, S.E, S.F), therefore to different acetic acid concentrations.

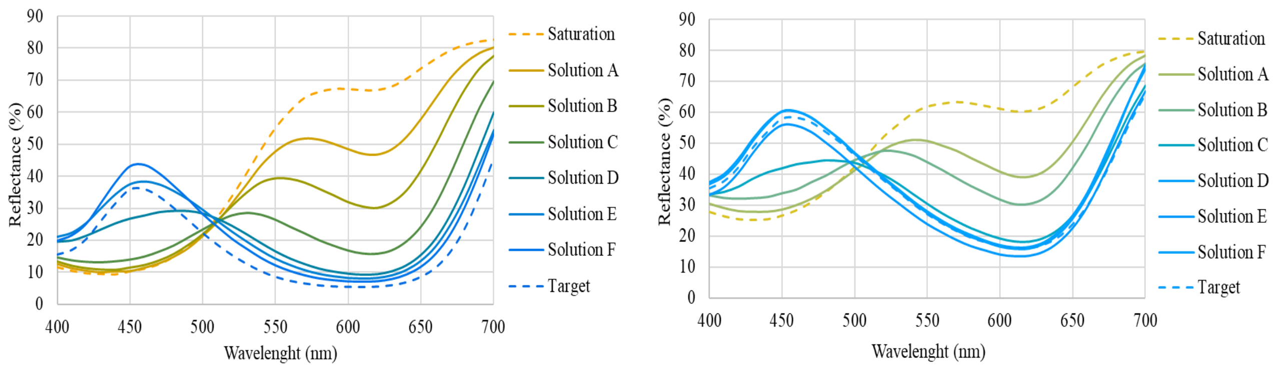

Fig. 2 - IPI AD Strips® (left) and Dancheck AD Strips® (right) reflectance spectra for the six solutions (S.A, S.B, S.C., S.D, S.E, S.F) and for target (blue) and saturated passive samplers (yellow).

Relationship between colour change and AA concentration

Two fitting curves were derived for IPI AD Strips® and Dancheck AD Strips®, respectively (Figure 3), by plotting the colour change of AD strips exposed for 24 hours to the six solutions against related AA concentrations. The less common C.I.E. L*C*h Colour Space was used, in parallel to the more traditional C.I.E. L*a*b* Colour Space, due to the former's better suitability in reflecting the way the human eye perceives colours. Therefore, it was preferred to express the

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colour change in terms of the difference in the hue colorimetric coordinate (Δ*h*) instead of the difference in the yellowness value investigated in the literature (Δb*) (Hackney, 2016). In this context, it should be remarked that *h* is the hue corresponding to an angle expressed in degrees ranging from 0° to 360°, i.e., 0° is +a* = red, 90° is +b* = yellow, 180° is -a* = green, and 270° is -b* = blue). Changes in C* (range 21 to 49 for IPI AD Strips®, range 15 to 32 for Dancheck AD Strips®), as well as changes in a* (range from -15 to +4 for IPI AD Strips®, range from -15 to -9 for Dancheck AD Strips®), do not give a useful response for the AD strips' colour changes and are not discussed here. The gaseous concentrations of AA simulated in the climate chamber (gas phase in equilibrium with the liquid phase, i.e., AA solutions) was explicated instead of the pH (Hackney, 2016). Considering the y axis as a linear scale (*h*) and the x axis as a logarithmic scale (AA concentration in ppb), a sigmoid curve was obtained, characterized by an initial lag phase (i), followed by an exponential growth phase (ii), and a final plateau phase (iii). This curve perfectly describes the VS affecting cellulose acetate films: (i) the film is stable, (ii) the triggered decay process tends to proceed rapidly as well as the rate of AA emission tends to increase. The saturation of the AD strip corresponds to the final stationary phase (iii). The asymptote for both brands of AD strips would be the saturation limit (yellow colour), corresponding to an AA concentration above 53000 ppb, not yet obtained with our AA solutions. It is worth noticing that the third phase is visible in the sigmoid curve of IPI AD Strips® but not in that of Dancheck AD Strips®, which still tends to grow for 53000 ppb. In Figure 3, the autocatalytic AA concentration range (i.e., 3000-5000 ppb) is highlighted by dotted white lines, also displaying the related *h* ranges. In the case of Dancheck AD Strips®, it visibly corresponds to a blue-green colour (h = 250 to 220), while for IPI AD Strips® it is in the green region (h = 220 to 130). The uncertainty associated with the *h* values in the fitting curves was graphically represented by drawing the line as a band (for IPI AD Strips® standard deviation = 0.8 to 2.5 and maximum absolute error = 1.1 to 3.1; while for Dancheck AD Strips® standard deviation = 0.2 to 3.9 and maximum absolute error = 0.2 to 4.4).

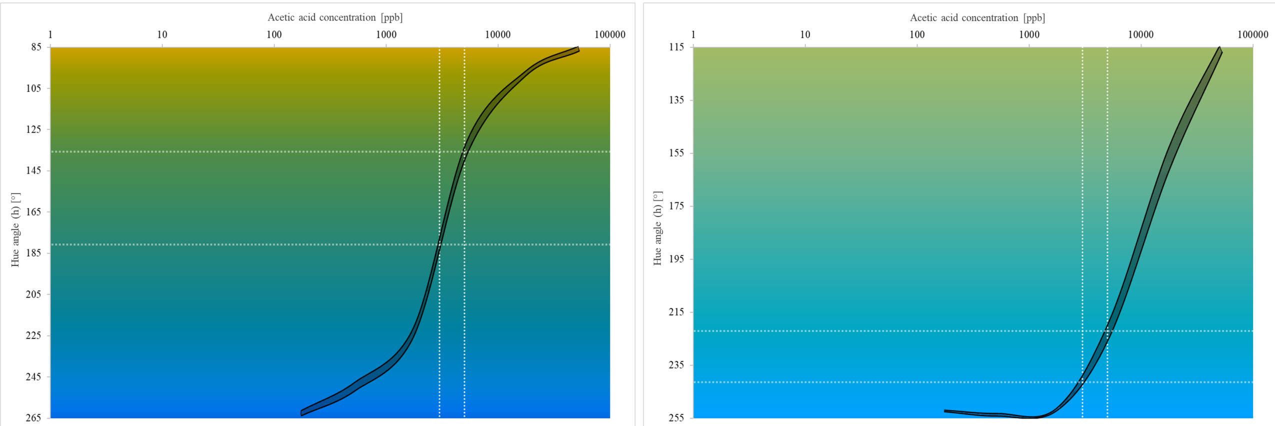

Fig. 3 - Sigmoid model (black) depicting the concentration of acetic acid (ppb) against the corresponding colour change of IPI AD Strips® (left) and Dancheck AD Strips® (right) expressed in terms of *h*. Hue variation was measured by spectrophotocolorimetry. The range of autocatalytic point (3000-5000 ppb in according to IPI) was reported (white).

Application to the case study

Finally, we present the preliminary results of the *in situ* campaign carried out at the CSC in May 2023. Figure 4 shows the films (black dots) as a function of shrinkage from their original size (x-axis) and the Dancheck AD Strip® colour measurement after a 24-hour exposure within their can (y-axis).

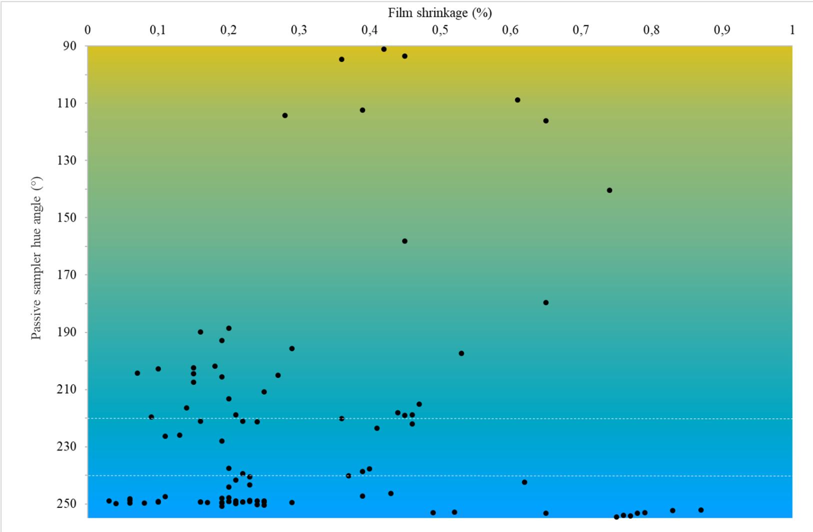

Fig. 4 - Correlation of the film shrinkage and the hue value (*h*) of 24-hour exposed Dancheck AD Strips® measured by spectrophotocolorimetry within film can. Each black dot represents a cellulose acetate film stored at CSC archive. The range of autocatalytic point (colour change corresponding to AA concentration of 3000 to 5000 ppb) was reported (white).

It can be observed that most of the films are in an optimal or good preservation state, as the outputs of the screening of the 100 films prove that about 55% of them release less AA than the amount corresponding to the starting of the autocatalytic range (while about 15% drop into the range of autocatalysis). Intermediate shrinkage values (between 0.2 and 0.8%) were measured in less than 10% of selected films affected by more advanced VS stages, whereas the majority of the unaffected films show no or minimal shrinkage. Considering the few unaffected films with high shrinkage values, the shrinkage may be attributed to other causes (here not investigated yet), but not to the presence of VS.

Conclusions and future research

This contribution represents an implementation of colour measurements performed on acid-base indicator paper strips commonly employed as non-destructive field tests in archives for the qualitative survey of VS affecting cellulose acetate films. We provided both a fitting sigmoid curve, that allows to relate the colour change of two brands of acid-base indicator papers directly to the emission of gaseous AA within the film can by the VS-affected film itself, and a continuous colour reference instead of the discontinuous standard colour scale provided by strip manufacturers. In this way, film conservators will be able to perform colour measurements with portable spectrophotometers (i.e., hue of the strip as output to be investigated), or simply slide the strip along the continuous colour reference until it matches the most similar colour, then read the AA concentration corresponding to that colour. One caution imposed by time constraints should be noted: if exposure of the AD strip to gaseous AA is short (i.e., 24 hours), there is a risk of an erroneous reading due to quick colour reversion (towards blue/green colour, not the original blue due to the reaction of some sodium hydroxide) caused by evaporation of the absorbed volatile AA. For this reason, the colorimetric measurement must be taken instantaneously after removing the AD strip from the can. However, confidence in the results can be gained by extending the exposure (i.e., 3-7 days under room conditions) to stabilise the colour, thus drastically reducing the risk, and allowing the reading to be taken directly in the archive laboratory. The objective quantification of the concentration of AA accumulated within the can as emitted from the film, more or less affected by VS, makes it possible to understand whether or not the film is beyond the autocatalytic point, with the possibility of an effective early warning damage sensor to make timely choices to safeguard single films or collections based on an assessment of storage preservation conditions. A classification protocol according to films' AA emission and/or degradation level of films would also be achievable. The preliminary campaign conducted at the CSC archive demonstrated the effectiveness of the proposed methodology for assessing the AA emitted by films on the basis of colour change of exposed strips, going deeper into the investigation by correlating the VS stage with the shrinkage of the film itself. Future studies will be devoted to investigating cellulose acetate film base at different VS stages in order to validate the proposed procedure and to relate the amount of AA released with the macroscopic characteristics of the film observable in archives. The preliminary study conducted *in situ* at the CSC will be implemented by repeating the campaign on a larger number of samples using Dancheck AD Strips® coupled with IPI AD Strips®. The confidence evaluation of the colour measurements of the two strip brands will confirm or deny whether the fitting curves return same AA concentrations for same films, although colour gradients are visibly different.

Acknowledgments
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Digital analysis of early color photographs taken using regular color screen processes

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Abstract
Some early color photographic processes based on special color screen filters pose specific challenges in their digitization and digital presentation. Those challenges include dynamic range, resolution, and the difficulty of stitching geometrically–repeating patterns. We describe a novel method used to digitize the collection of early color photographs at the National Geographic Society which makes use of a custom open-source software tool to analyze and precisely stitch regular color screen processes.

Keywords: Early color photography, National Geographic Society, Dufaycolor, Finlay Colour plate, Paget Colour plate, digitization of color photographs

Introduction

Several commercially produced processes of early color photography (used in 1890s to 1950s) were based on special *color screen* filters consisting of small *patches* of red, green, and blue color (Fig 3a). The filter was either an integral part of the photographic film or attached on top of the panchromatic negative before taking the picture. After development, monochromatic transparency was produced. When registered with the color screen filter it yields a color photograph. Most common examples of these processes include Autochrome, Agfacolor, Dufaycolor, Paget and Finlay color plates. The first two use random (or stochastic) color patterns, while the remaining use periodic geometrical patterns similar to modern Bayer filter used in digital cameras (Lavédrine and Gandolfo, 2013), (Pénichon, 2013). We call those processes *regular color screen processes*.

Digitization of color screen processes has high demands on the quality of digital captures. It is necessary to digitize large format originals in multiple captures and later stitch individual tiles to a high-resolution image. This task has turned out to be impossible to do with usual panorama stitching tools since small errors in the registration of individual tiles lead to easily noticeable artifacts visible in the regular color screen pattern.

We describe practical experience with digitizing collections of photographs taken using Dufaycolor film, Paget, and Finlay color plates at the National Geographic Society by digitization service provider Digital Transitions and using specialized open-source tool Color-Screen.

Early color photography collection at National Geographic Society

Founded in 1888, the National Geographic Society is a 501 c3 non-profit that uses the power of science, exploration, education and storytelling to illuminate and protect the wonder of our world. Photography is a major part of that history, including contributing to technical photographic advancements in addition to its memorable images seen by the public.

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The Society was no stranger to color photography when the Autochrome first arrived. Invented by Lumière brothers, the Autochrome was the first industrialized color photographic process – before this nearly all color photographs were made so by hand tinting. The National Geographic Magazine had already been publishing those hand tinted photos in color, and editors were incredibly excited for a photograph that captured colors seen by human eyes. Though the Society was first interested in Autochromes, it quickly acquired many examples of other processes Agfacolor, Dufaycolor, Finlay and Paget color plates.

In total, the Society has one of the largest collections of screen plate photography in the world at over 15,000 plates documenting many parts of the globe. These photographs were used by the Geographic to illustrate magazine stories until the invention of Kodachrome film in the mid 1930s.

In 2020, the Society began the Early Color Photography Conservation and Digitization Project made possible in part by a major grant from the National Endowment for the Humanities: *Democracy demands wisdom*. The project was broken down into two phases: *Phase One – Conservation* and *Phase Two – Digitization*.

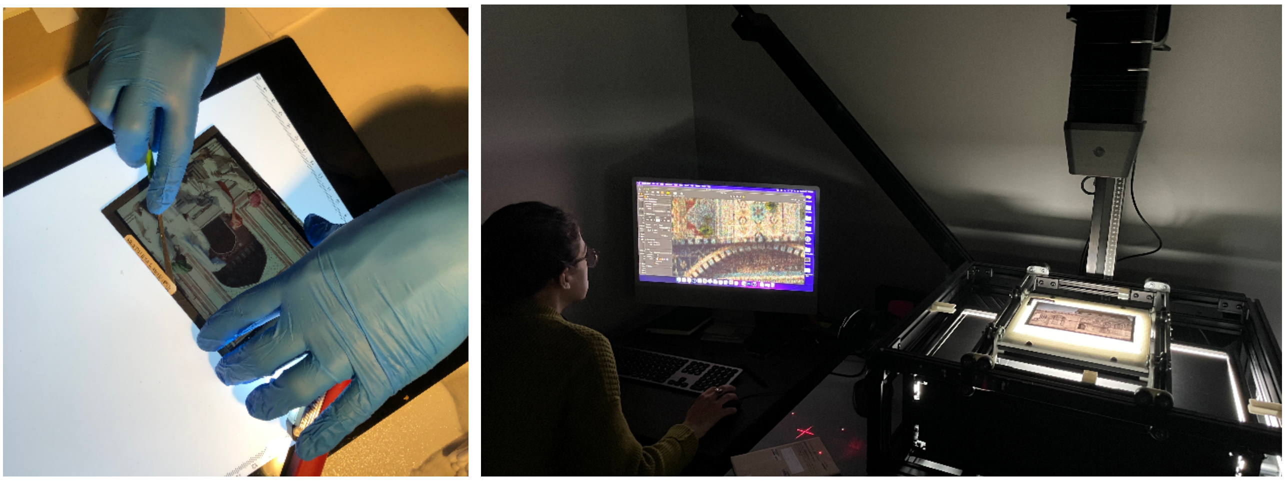

Fig. 2 – Conservation (left) and digitization (right)

During Phase One, the Society collaborated with the Conservation Center for Art and Historic Artifacts (CCAHA) to conserve each photograph in this collection. The objects were cleaned of fingerprints, dust, and pollutants such as cigarette smoke prior to digitization. Just under 400 items were transported to CCAHA for in depth treatment including glass replacement or puzzling back together items broken into several pieces. A particularly important factor in this work was the type of glass used for repair. Borosilicate and plexi were both chosen because they will not create newton rings in the digitized image. As we were conserving the Dufaycolor plates, we discovered they had developed vinegar syndrome. The Dufays were stored near negatives with vinegar syndrome for many years, and the acetic acid seeped through the tape and in between the two pieces of glass in all Dufays to cause the classic vinegar syndrome symptoms: cracking of the film base, warping of the emulsion, a strong vinegar smell, and dyes forming bright purple spots (Siegel, 2003). There is no conservation treatment to reverse this type of deterioration, and the cracking and warping posed some challenges during the digitization.

During Phase Two, the Society collaborated with Digital Transitions Heritage (DT) to digitize each photograph. In order to create the most detailed image, each object was digitized in sections and stitched together in the post-process workflow. Every stitched file was quality checked with a 3–5% targeted fail rate ensuring accurate color reproduction and high quality stitching in the final product. Failed stitching exhibited at least one of the following qualities: a stitch line throughout the photograph, color and/or tonal differences between the tiles, and misaligned content of the image. For those that failed, manual stitching fixed most of the errors and images containing large blocks of color (such as a blue cloudless sky) were some of the hardest to stitch. But as we discuss below the Dufaycolor photographs presented their own unique challenge in the stitching process.

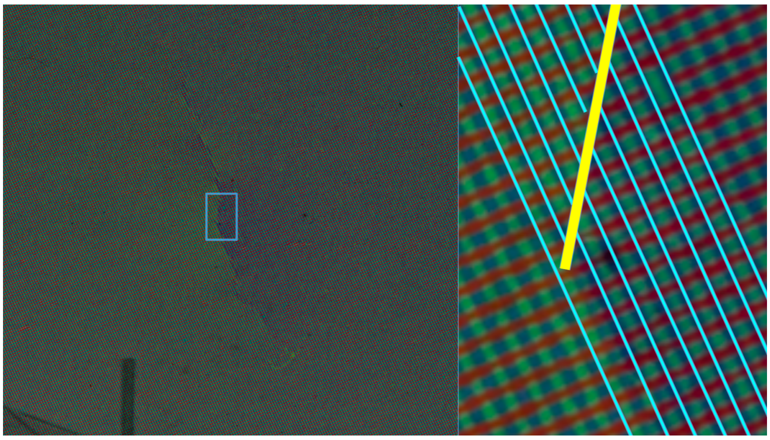

Fig. 2 – Stitching errors are visible as both tears in the geometrical grid as well as color changes.

The Society will store in its DAMS (Digital Asset Management System, which is backed up in the cloud) each tile, the stitched master TIFF, the content reproduction JPEG, and delivery JPEG for each photographic object. Though the content reproduction and the delivery jpegs will be accessed by users the most, each tile is kept as a master reference and for possible restitching in the future without having to re-digitize the original photograph. Each file is embedded with IPTC metadata notes about the stitching and other post-processing information unique to this project.

Digitization Technical Parameters

Digitization of these materials requires very high image quality, especially if the results will be used in computational imaging techniques such as stitching or color screen demosaicing. While an exhaustive list of image quality parameters and digitization technique is out of scope for this paper, three such parameters are of special interest: resolution, dynamic range, and geometry.

It is vital that the resolution of the capture out resolve the physical pattern. Otherwise, the screen pattern cannot be cleanly resolved by the eye, and may be misdetected by an algorithm. Digital Transitions conducted research with National Geographic in 2019 which established baseline PPI requirements for each early color process in their collection. By far the most demanding was Dufaycolor which required 4400 ppi to cleanly resolve the screen. This means that for a 5×7 inch plate (with 0.25 inch padding) roughly $22{,}000 \times 33{,}000$ pixels is required for the plate, which means even a 150 megapixel capture device must capture the plate in tiles. It is also important that these pixels represent sharp and homogenous detail across the frame; that is, in signal processing terms, a high sampling efficiency is required throughout the frame. We used the ISO 19264 and FADGI 2023 imaging guidelines to select appropriate SFR10, SFR50, and SFRmax aim values (Rieger *et al.*, 2023).

It is also important that the captures be high in dynamic range (high bit depth + low noise). This is primarily because such plates are often very dense (high optical density; low transmittance; dark) and because it is standard archival practice to set exposure such that the white point is the naked light source. However, it is also because the colorants of the screen pattern closely align to the Bayer pattern of the sensor, and therefore each plate pixel is primarily recorded only with its corresponding digital sensor pixel. For example, a very dark red line of a Dufay plate will only be properly seen by the red pixels of the digitization system's Bayer filter; the green and blue pixels of the digitization system will record no meaningful signal (only the noise floor). This is always a problem in digital imaging, but the highly saturated primary-color nature of the mosaic plates is a worst-case scenario.

Finally, it is important to minimize systematic geometric distortions. The Color-Screen tool will account for all manner of distortions including non-planarity and lens distortion, and has even been adapted to account for scanner-drag (uneven spatial stepping due to variation in the movement of a scanner that moves a scan head during digitization). However, the more distortions in the imaging system the wider the tolerances Color-Screen must allow, which increases the chance of failures.

Based on these technical requirements DT selected the DT Atom with a 150mp DT RCam, and built a custom high-precision XY accessory. We calibrated the system with a DT LaserAlign and checked the homogeneity of detail using an ISA Golden Thread Film Target. This system features a lockable focus ring, which eliminates focus drift (a common occurrence with general purpose cameras when you point the lens downward). A DT technician, Kenzie Klaeser, familiar with the system, operated the system throughout the project until its conclusion in September 2023, assisted by various members of the National Geographic Society.

Color-Screen tool

Color-Screen[1] is an open-source tool for digital processing of scans of photographs taken using color screen processes. In 2010 Mark Jacobs and Jan Hubička noticed scans of Finlay color negatives in the American Colony Collection at the Library of Congress. After many unsuccessful attempts to register the scans with viewing screen in GIMP and Photoshop, Jan implemented a prototype of a specialized tool. First color reconstructions were shown at 2011 exhibition "The American Colony in Jerusalem and the Matson Photo Service" at the Šechtl and Voseček Museum of Photography in Tábor, Czech Republic. Due to lack of scans of similar negatives, the project was put on hold until 2022 when Linda Kimrová joined the project and new collections of similar early color photographs were found, see (Barker *et al.*, 2022) for list.

Accurate color reconstruction from monochromatic negatives requires understanding of spectra of original dyes. These are known for Dufaycolor (Cornwell-Clyne, 1951). For Autochrome modern analysis was performed based on recreated dyes (Lavédrine, 1992), (Casella and Tsukada, 2012). We are not aware of similar study of Finlay and Paget screens. Modern spectral measurements (Trumpy *et al.*, 2021) provides useful data and can be used to simulate aging of the image as well as making "educated guess" on the original colors.

Color-Screen is useful also when digitizing final transparencies with color screens attached. Since dyes used in the screen filters are not very stable, most positives appear very faded. In some cases, the registration between the black and white transparency and the screen has been lost which leads to complete or partial color loss of the image. Unlike for later subtractive color films, in the color screen processes the original image is recorded in silver-gelatine transparency which is stable and can be digitized in infrared spectra (dyes used in the viewing screen are transparent in infrared scans). This enables Color-Screen to accurately reconstruct original colors from scans.

Even with a specialized GUI, registering screens manually is a time-consuming process (main challenge poses numerous geometric errors in the scans as well as aging of the film base or flaking of the emulsion). Work on automatic analysis of screens based on the scans started in 2022.

[1] https://github.com/janhubicka/Color-Screen/wiki

Extending Color-Screen to stitch high resolution scans

While not originally intended to be used to stitch scans, it was clear that algorithms used to analyze geometry of the color screens can be useful to assist image stitching software.

Our tool works in three basic steps: 1) it analyzes every tile independently, 2) it solves the stitching problem and 3) renders individual tiles of the output image to be blended by separate software.

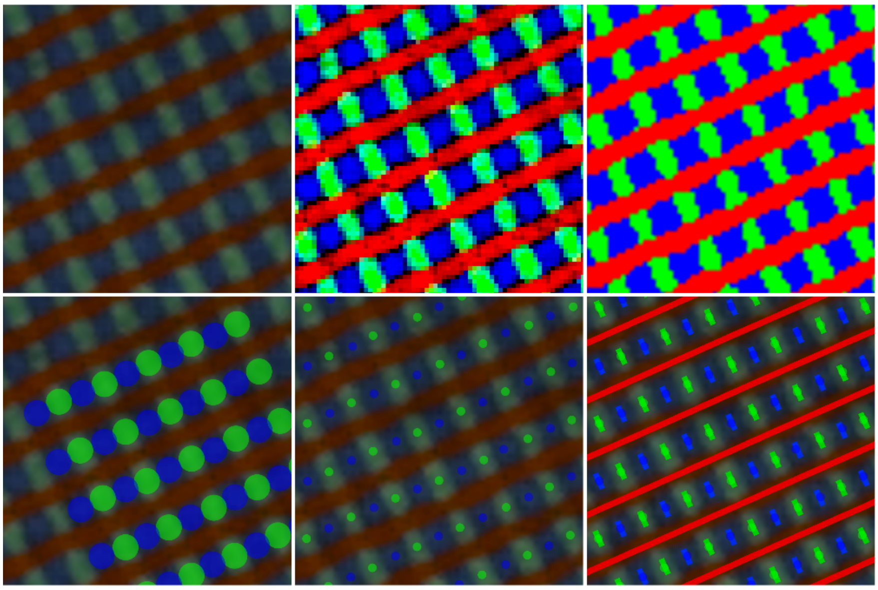

Fig. 3 – Dufaycolor color screen and its analysis. a) original screen, b) screen after analysis of color filters, c) screen after identification of red, green and blue patches, d) detected grid of blue and green patches, e) result of flood fill, f) result of RANSAC mesh construction

The first part of the analysis is most involved and divided into the following steps:

Color linearization: Image is converted from input profile to linear RGB. It is important to work with scans close to their raw form without any digital enhancement algorithms applied (such as tone curve, sharpening, noise reduction, color space conversions) except for demosaicing (Fig. 3a).

Analysis of color filters: A sample of image in the center of scan is analyzed identifying 10% of most red, blue and green pixels. These are used to build "matrix profile" of the original screen. This is done by estimating 3-dimensional vectors $\vec{d}$, $\vec{r}$, $\vec{g}$, $\vec{b}$. Vector $\vec{d}$ determines black point of the scan, while vectors $\vec{r}$, $\vec{g}$, $\vec{b}$ determines color of the red, green and blue filters of the color screen as interpreted by the digital scan. Ideally all samples of red color should be in the form $\vec{d} + \vec{r}x$, where x is a scalar variable. Similarly for blue and green samples. Result is a 4×4 matrix M. Based on the matrix M the image is converted from its original linearized RGB to RGB values which correspond to the estimated profile (Fig. 3b) and unsharp-mask is applied.

Identification of red, green and blue patches: Given pixel with color (r, g, b) if $r > |g + b|t$ for a fixed threshold t we consider given pixel to be red. Similarly for green and blue (Fig. 3c).

Detection of the geometry of color screen: This step depends on a particular color screen. For Dufaycolor screen first a continuous area of green pixels is found. Because of the organization of the Dufaycolor screen it is expected that neighboring areas (patch) will be blue. Based on the center of mass of the two neighboring patches it estimates the orientation and scale of the screen. Next algorithm looks for a regular grid of 5×5 of pairs of green and blue patches gradually improving estimates of the screen geometry (Fig. 3d). Analysis Paget and Finlay screens is similar.

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Flood fill: The parameters determined are not precise enough to register full scan with the color screen, however they are quite good locally. To determine as many color patches as possible the algorithm extending classical flood-fill is used. Based on knowledge of one-color patch and estimated geometry, neighboring patches are detected and recursively also neighbors of the neighbors etc. While not all patches are rendered well on the scans, in a good scan over 95% of patches can be identified. This step is most important for getting good match between the screen and the scan. While it seems easy, it is important to not make off-by-one errors while walking millions of patches and this required significant amount of fine-tuning.

Mesh construction: Result of the flood-fill algorithm never fully perfect. Some patches are missing, and the centers of patches are not very well computed. This problem can however be solved by simple statistical tools. We implement standard Random sample consensus (RANSAC) algorithm to determine homography between the color screen and identified color patches. With additional lens correction this produces good results for scans of photographs on glass (Paget and Finlay).

Dufaycolor has film base which is deformed due to its deterioration. To solve this problem, we run RANSAC solver in a grid of 100×100 points over the area of the scan each time setting weight of individual detected patches to decrease by the distance from the center of the point analyzed. Smoothly interpolating the solution leads to an adaptive model that is flexible enough to follow the deformed grid on film bases and still understand the fact that locally the transformation should correspond to a homographic map.

Data collection: Once the location of each color patch is identified, its intensity is determined from the original scan. The result is a mosaiced digital image in the natural resolution of the color screen, each patch corresponding to one pixel, which is later used in the stitching process.

Each of the steps may fail if the algorithm gets confused by some defects or irregularity of the image (such as broken part of the image, hand retouching, very dark area etc.). If Flood fill algorithm fails to analyze important part of the scan the process is repeated starting from different location than the center of the scan.

Once all tiles of the scan are analyzed, the stitching is performed using standard open-source tool cpfind[2] based on a demosaiced version of image produced in data collection (just as in digital photograph). Once matching points between scans are identified Color-Screen applies an inverse mesh transform to identify matching points in the original scan. These can be inserted to an open-source panorama stitching tool Hugin[3].

Pairs of matching points identified are significantly more precise than ones done by general-purpose panorama stitching tool. Yet it turned out that using Hugin to produce final scan is leading to stitching artifacts. In our test samples the average point distance was in the range 0.5–1.3 pixels and maximal distance 5–11 pixels. While this precision would be acceptable for production of normal panorama, with average size of a color patch in the scan being just 5 pixels, such displacements are easily visible and moreover they confuse color blending algorithms (Fig. 2).

Detailed analysis showed that this problem is related to the film flatness. Dufaycolor transparencies were sandwiched between two glass plates. Even in this setup the film flatness is not perfect and since each tile scans the film from a different angle, this leads to complex geometrical errors. Other

[2] https://wiki.panotools.org/Cpfind
[3] https://hugin.sourceforge.io/

common source of a problem are vibrations of camera during the capture. For this reason, stitching using homographic transformations and lens corrections fails.

Instead of relying on the standard image stitching algorithms we implemented an algorithm that produces geometrically corrected image based on the transformation mesh constructed in the initial stage. This corrects both the deformations caused by digital capture process as well as the deformations caused by aging of the film base.

The final problem to solve was blending of individual tiles. Even with calibrated backlighting, the tiles do not match in color and density. This is caused by the fact that there is a space between the photographic emulsion and color screen and thus different capture angles lead to different colors. We adapted open-source tool multiblend[4] for this purpose.

Fig. 4 – Walter Reed General Hospital by Willard Culver, 1936. Successful stitch (left). With demosaic and color reconstruction (right).

Production Integration

Color-Screen is a command line tool that handles one photographic image at a time. The large National Geographic Collection required a more scalable implementation. So, Color-Screen was integrated into an imaging pipeline called DT PixelFlow used by Digital Transitions to automate stitching as one of several steps in the production process. Specifically, DT PixelFlow converted the camera raw files to TIFFs, renamed them to comport to Color-Screen's expectations, called Color-Screen, added metadata to the resulting files, and created additional derivatives such as a JPEG that was visually reviewed by a quality control technician, and a TIFF with an automatic brightening adjustment applied to make dense plates more legible.

Conclusions and Future work

The primary goal has been to develop a method to digitally capture regular color screen processes in a resolution which faithfully record their mosaiced nature. This is pushing current digital imaging to limits, however the fact that Color-Screen tool can analyze the scan and identify individual color patches serves also as a proof that this goal has been established.

Tools developed have multiple additional uses.

[4] https://horman.net/multiblend/

1) Because it precisely analyzes the viewing screen it is possible to apply demosaicing and produce high resolution images that are more fit for printing and viewing on common digital screens than their mosaiced originals.
2) Using the knowledge of spectra of dyes used in Dufaycolor screen it is also possible to attempt careful color reconstructions of the captured images. Ideally this should be based on scans which include red, green, blue and infrared channels. However even without infrared scan a limited-quality reconstruction is possible (Fig. 4)
3) It is possible to identify different variants of color screens used. In the National Geographic Society collection two types of Dufaycolor images are used which differ by size and angle of the individual lines forming the color screen. This difference appears to not be discussed in literature, yet.

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Ozaphan films: preliminary study on color analysis and digitization

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Abstract

Ozaphan is a historical type of motion picture film made of cellophane, which exploits a silverless printing technique called diazotype used only for positive prints. These films were produced in the late 1920s up to the 1950s, initially in France and later in Germany, catering mainly to the home cinema market and therefore being printed primarily on small gauges. Ozaphan films were intended to be black-and-white films but ended up with a characteristic yellow hue due to the phloroglucinol used in the photosensitive solution.

Although Ozaphan films were produced in relatively small quantities, we still find these prints in many European film archives today. Nonetheless, not much research has been carried out on this film material's conservation and physical characteristics.

This study aims to document Ozaphan's color characteristics by presenting an in-depth color analysis of the latter, achieved mainly through spectrophotometric instrumentation. The measurements have been carried out both on the light parts as well as on the dark parts of the frames to try and identify the exact hues of the yellow tendency of the prints. These types of colorimetric measurements can be firstly a relevant record of the current state of preservation of the films and secondly a reference during digitization and future digital restorations.

Digitization certainly is a valuable tool for preserving and distributing audiovisual heritage. However, it involves modifying or excessively approximating the representation of some intrinsic characteristics of the materials, like colors. Thus, the second step in this study has been the attempt to apply the measurements of the transmittance color values both during scanning and the subsequent color correction phase to digitally preserve the actual hues of the Ozaphan films.

Though still experimental, the results can be a useful hint for the approach to scanning, and the colorimetric measurements are a reference for further studies of Ozaphan films.

Keywords: Ozaphan, Film Restoration, Cultural Heritage, Color in Films

Introduction

The historical origins of Ozaphan films emerged from the convergence of two pioneering inventions: cellophane, a transparent regenerated cellulose foil, and the dry diazotype process, a positive-working reprographic method that involves the photosensitivity of diazonium salts and azo dye synthesis.

During the early 1920s, Société Anonyme Le Cellophane in France conducted experimental endeavors, applying the diazo print process onto cellophane film strips. Subsequently, a more robust framework for Ozaphan film production took shape through a procedural exchange between Kalle & Co. AG and La Cellophane. This agreement permitted Kalle & Co. AG to exploit cellophane in certain regions while enabling La Cellophane to utilize the Ozalid procedure.

In France, the Ozaphan films were first sold in 1928 and in the following years, different gauges were released such as 17,5 mm, 22 mm, 24 mm and 35 mm.

Within Germany, Kalle & Co. AG assumed the exclusive production of Ozaphan film stock and introduced it to the market around 1932 as a 16 mm format for the distribution of a segment of Agfa's home movie catalogue. The Ozaphan catalogues, predominantly encompassing fairytales, documentaries, animation, and comedies, were tailored to family audiences.

From 1934 and 1940, the monthly newsreel series *Schmalfilm Monatsschau* was distributed. These materials were under propagandistic influence, especially after an agreement between Kalle and UFA.

The Ozaphan film production ceased in June 1940 due to cellophane shortage and wartime demands on Kalle's workforce.

After World War II, Germany's film industry faced challenges due to the destruction of establishments and Allied control over distribution. In 1949, a new Ozaphan film program emerged, and a small number of 8 mm films were printed; nonetheless, production issues and the technological advancements of other film stocks led to a fast decline in the late 1950s. This resulted in the discontinuation of the Ozaphan production in 1958.

The process for the production of Ozaphan films can be explained in four steps[5]:

1. Sensitizing: In a dark room, the cellophane sheets were immersed in a light-sensitive solution composed mainly of diazonium cations[6], dye couplers[7], and acid stabilizers; the latter prevents pre-coupling between the couplers and the diazo cations.
   Depending on the color that was to be achieved, different types of couplers could be chosen. A diazo solution can contain more than one coupler which, for example, is necessary to obtain a black image, even though it is not possible to get a dense black.
2. Printing: The exposure of the films happened with a contact printer. The light transmitted through the clear parts of the image, onto the diazo coating, started the photolysis of the diazonium salts. Their decomposition left a clear or light part on the film. On the other hand, where the dark sections of the master didn't allow the light to shine through, the diazo salts stayed intact and maintained their coupling abilities.
3. Developing and toning: The development of the films took place in an autoclave where ammonia gas was introduced. This process made the pressure chamber environment alkaline, causing the neutralization of the acid stabilizer and allowing the coupling between the dye coupler and the diazo cations to occur. This resulted in the final formation of the azo dyes. A toning period was set up to define the nuances of the contrast better. This happened through steam distillation in the ammoniac-filled autoclave, and by regulating the duration and pressure of the film's permanence in the autoclave. In general, diazo films have a limited tonal range.

[5] The process refers to the method used to print on 16 mm cellophane film at the laboratories of Kalle & Co. AG

[6] A type of organic compound resulting from a reaction of primary aromatic amines with nitrous acid and mineral acid called a diazotization. Two properties of the diazonium cations are relevant to this reprographic method. Firstly, their chemical instability that leads them to react with couplers. Secondly, their light sensitivity, that leads to the decomposition of the diazonium salts and the liberation of nitrogen gas on exposure to ultraviolet light, leaving an inert product unable to couple.

[7] Organic compounds that are colorless, but that produce colors when combined with the diazo salts. The type of coupler determines the achieved color: Phenols give a brown, red-brown, and yellow-brown dye, Naphthols a blue dye and compounds with an active methylene a yellow dye.

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4. Lacquer/coating: Since changes in humidity and temperature caused quite severe shrinkage of the material, the manufacturing included a coating phase. The film strips were coated either with a thin dip-lacquer or a highly concentrated stripping lacquer. According to documents from 1932 and a recipe from 1939, the most suitable coatings were nitrocellulose lacquers.

One physical characteristic of Ozaphan films that stands out is their yellow hue tendency, which is quite obvious when looking at light parts of the frames. Initially, the first thought regarding an explanation of this color tendency was the ageing of the material. However, the analysis of the monthly chemist's reports from Kalle & Co. AG pointed out that the yellow tone was a result of the phenol used during production. Kalle & Co. AG hoped to achieve a film as close as possible to regular black and white films, but after trying different diazo dyes, the phenol that gave the best results appeared to be phloroglucinol; even though, this compound left a yellowish image.

The dark parts of the frames, therefore, are also not black, but differently to the light parts of the images, determining the hue is not as straightforward. In fact, after asking a small group of people which color they would describe the dark parts as, the answer varied between grey, green, or even blue-purple.

With this study, we aim to document Ozaphan's color characteristics by presenting a spectrophotometric and colorimetric analysis of these materials and to assess if the characteristics of film colors can be preserved digitally.

Materials and Methods

The spectrophotometric analysis of the Ozaphan films was performed using an X-Rite Eye-One Pro spectrophotometer using the open-source software i1Toolz. The instrument was used for measuring both emissive and reflective light (380-730 nm, with 10 nm steps). The instrument's light source used for reflectance measures is a gas-filled tungsten lamp, while for transmittance measures, we used a backlit LED panel.

After acquiring the reflectance and transmittance data, the spectra have been converted in XYZ, and sRGB colorimetric coordinates.

For this preliminary study, seven 16 mm Ozaphan films were analyzed; for each one, spectrophotometric measurements were done both for a light part as well as for a dark part. The films varied in their dating between 1935 and the '50s, even though it wasn't possible to date them precisely. The films differed in their state of preservation, which in this case has not been specifically considered during testing but was kept in mind during the evaluation of the results.

The measured samples are the following:

ACHT (From the film *Acht Jungen und ein Ball*, dated after 1938, catalogue nr. 290).

HUE (From the film *Ein Hühnchen kommt zur Welt,* dated around 1935, catalogue nr. 14052/B).

1940 (From the newsreel *Monatsschau nr. 1940,* dated 1940).

GAL (From the film *Der Galante Schupo*, dated around 1935, catalogue nr. 11008/B).

1935 (From the newsreel *Monatsschau nr. 4 1935,* dated 1935).

GROOM (From the film *Le Groom Maladroit*, dated around 1938).

FALL (From the film *Fallenstellers Reinfall*, dated around 1950, catalogue nr. 269).

Results

It should be noted that the sensitivity of the sensor of the i1Pro Spectrophotometer for the transmitted light was slightly limited, therefore the graphs start from 420 nm.

Comparing the light parts

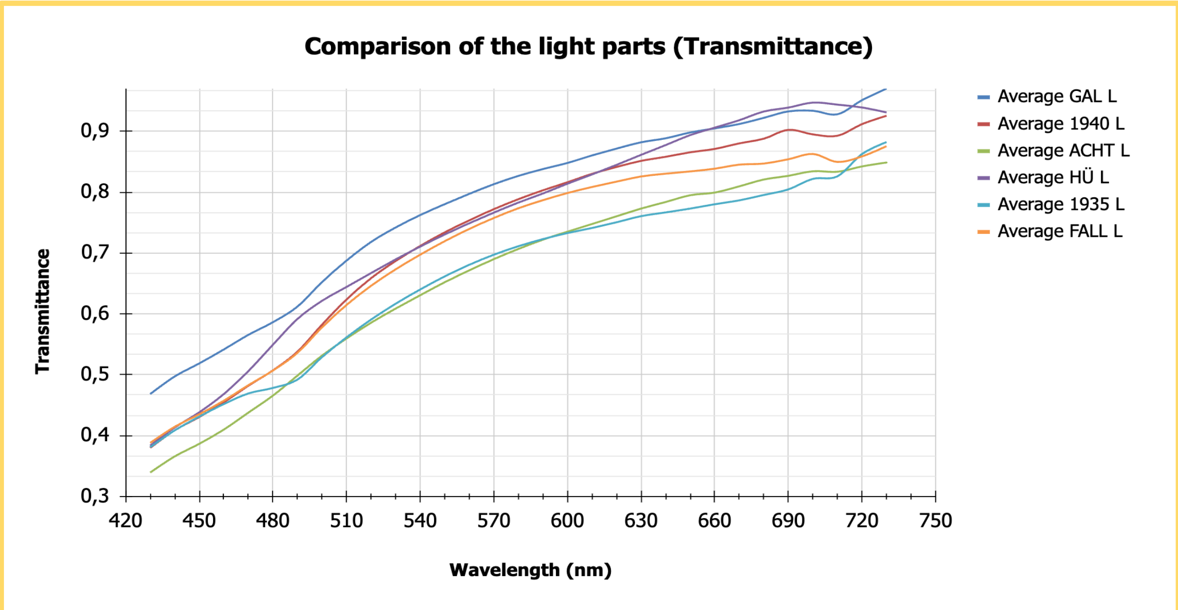

Table 1 - Transmittance of the light parts

From the comparison between the spectrums of the light parts from all samples, it is possible to immediately determine a generally rising trend, with only slight differences in the shape between the samples.

Four of the samples (GAL L, FALL L, 1940 L, ACHT L) show a change in the curve at 490-500 nm, where the spectrum stops having a relatively linear tendency and shows the start of a rise. This approximately corresponds with the peak of the color green at around 535 nm.

The spectrum of the sample "1935 L" is the one that showed up a bit differently. This difference is probably due to the part of the film that was selected for measurements for the light sample. The chosen frame was not completely clear and had some faint image parts, therefore more blue and green transmittance was captured.

Summing up, the transmittance of all samples is predominant between 500 nm and 740 nm, a range of light which is visible as going from green to red, therefore appearing as a yellowish light, with a slight red predominance. The difference in the light intensity could be attributed to different ageing stages or the presence of a patina of dirt on the films. For example, the film from the sample

"ACHT L", which showed up as less intense, did indeed have dirt residuals. Another hypothesis could be the different duration of the toning process, and therefore, different color intensity, as the process was probably never exactly the same.

For the film *Le Groom Maladroit* it has not been possible to measure a light sample, as no frame was considered suitable.

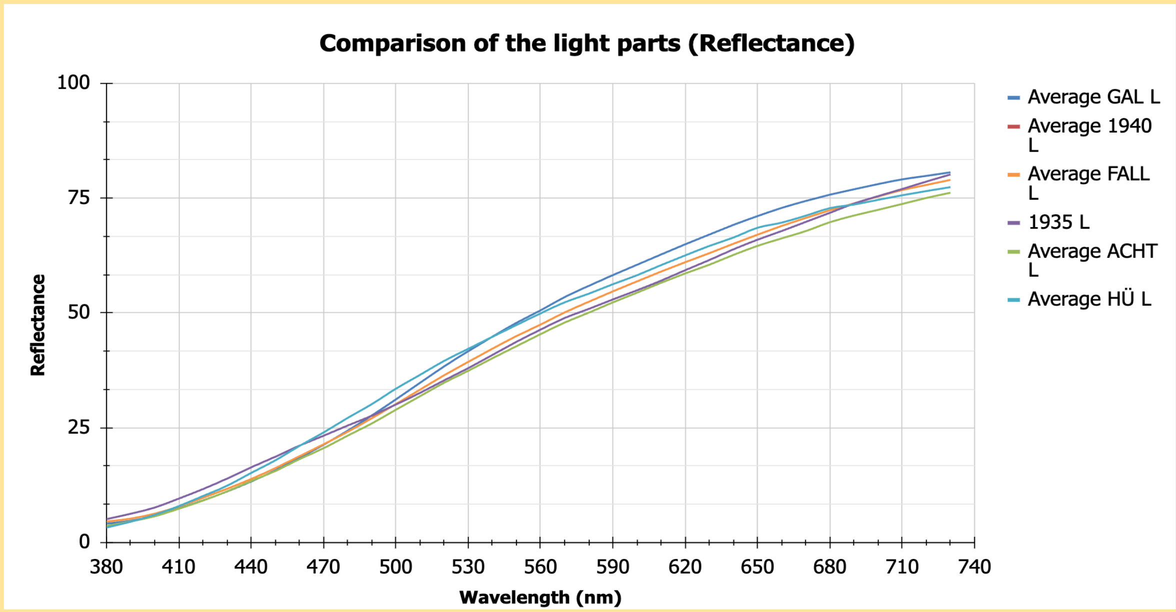

Table 2 - Reflectance of the light parts

The development of the transmittance curves and the reflectance curves proceed with a very similar trend. However, the reflectance curves are slightly more linear and don't show as much of a rise at 500 nm as do the transmittance curves.

Comparing the dark parts

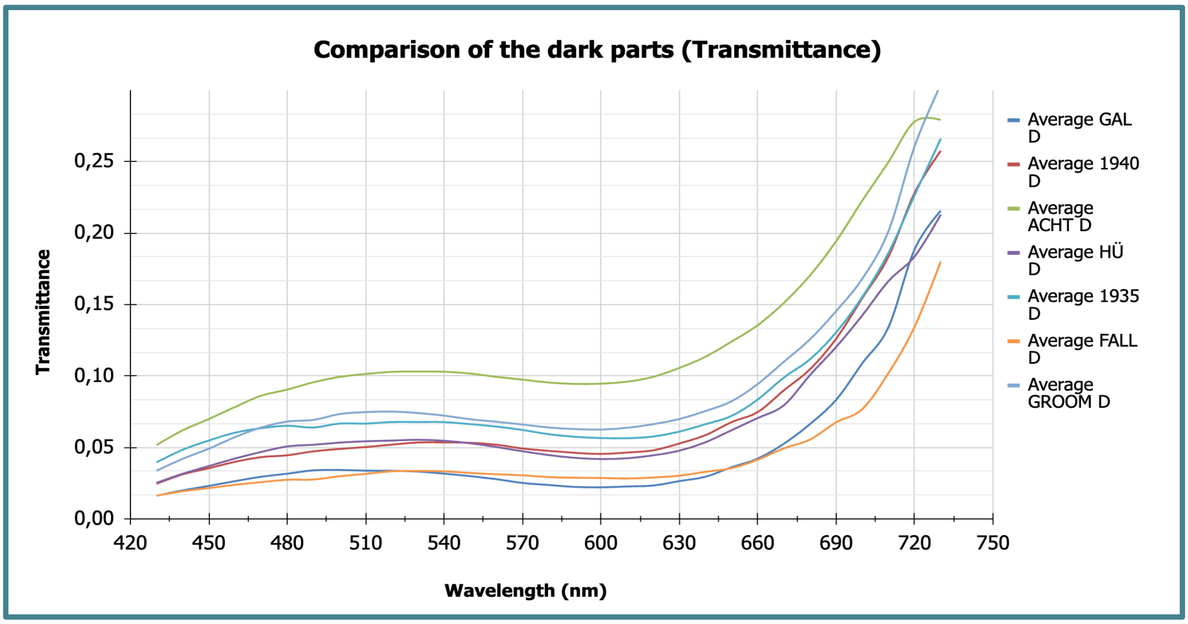

Table 3 - Transmittance of the dark parts

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The general trend of most of the curves reaches a first high point at around 500-530 nm followed by a slight decrease, which shows that the dark parts have in fact a green hue tendency. From 630 nm the curves rise very steeply. The presence of orange and red could be either due to the fact of the previously discussed yellow undertone, or more likely it could be traced back to the presence of writing, and thus light parts, that were inevitable to be included in the measurements due to the size of the spectrophotometer's sensor. This contamination is particularly evident when looking at the measurements of the "ACHT D" sample that showed up lighter; the frame that had been selected included a relatively large writing.

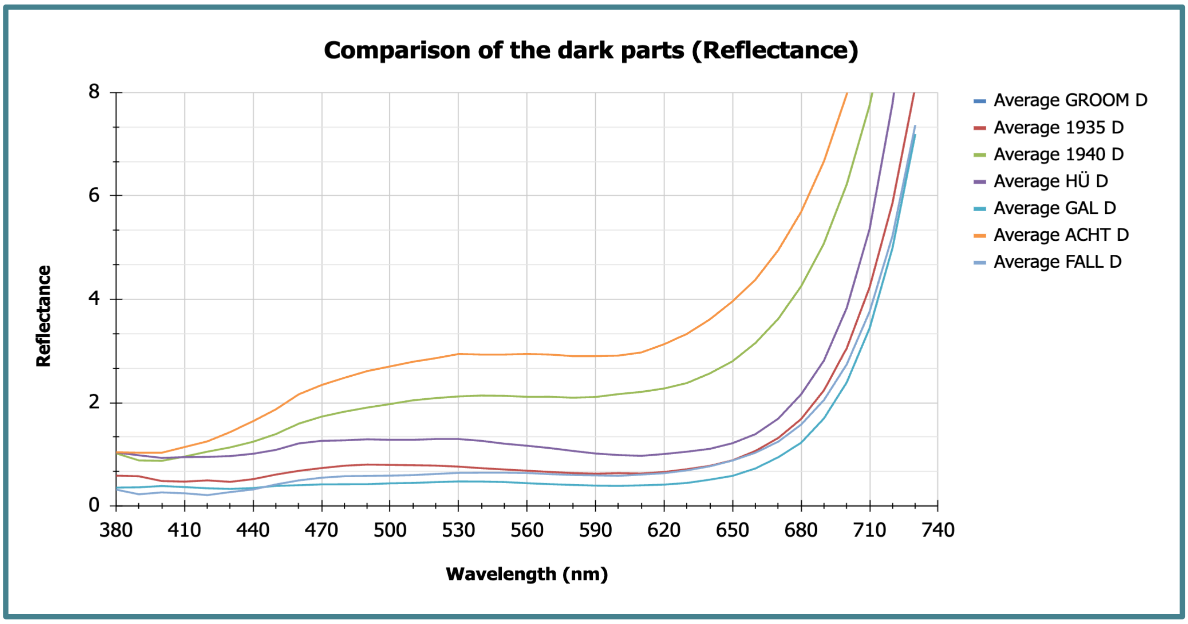


Table 4 - Reflectance of the dark parts

Just like for the light samples, when the development of the reflectance curves is compared to the ones of the transmittance curves, a clear correlation can be seen. The curve that stands out is the one from the "1940 D REF", for which the hypothesis of a human measuring error is plausible.

From Analog to Digital

During this study, four of the seven Ozaphan films that were used for the colorimetric measurements have been scanned. This has been an opportunity to experiment on how to try and preserve the colorimetric characteristic of the material as much as possible during the digitization and color correction. For this purpose, the computed RGB coordinates have been used to visualize the colors and can be used for comparison or as a reference. The goal was not to achieve the exact same RGB coordinates but to maintain the same balance between the three primary colors.

The Ozaphan films were scanned with the MWA Flashscan Nova scanner with a resolution of 2K and in 10 bits. It was evident already during the preview of the scan, that the colors represented in the digital image, didn't fully reflect the colors of the film material, they tended towards a warmer hue and with very little presence of green.

The first approach was to match the colorimetric values during scanning, but due to the limited control that the MWA software allows with the color wheels, this attempt was dropped.

The second approach that was attempted aimed at applying RGB coordinates during the color correction process with the software DaVinci Resolve. A useful tool was the color picker which allowed the RGB coordinates of the digital image to be analyzed, and then regulate the RGB channels to try and match them with the values computed from the spectral data. To explain the procedure, we report an example of color correction for the film *Der Galante Schupo*.

After the film digitization, the first step consisted of adjusting the contrast to regain tone depth. The second step was aimed at matching the light parts. The RGB channels for *Highlights* and *Gain* were modified separately to reach a balance as close as possible to the reference RGB coordinates.

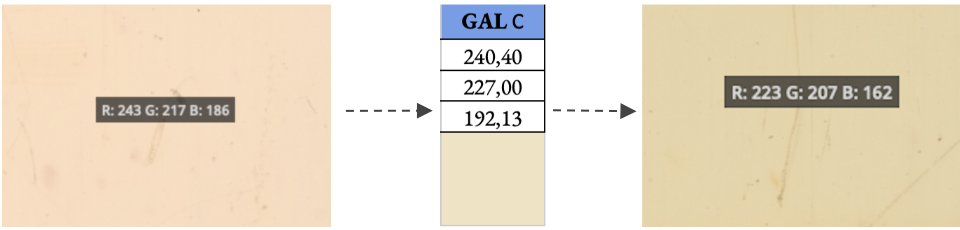
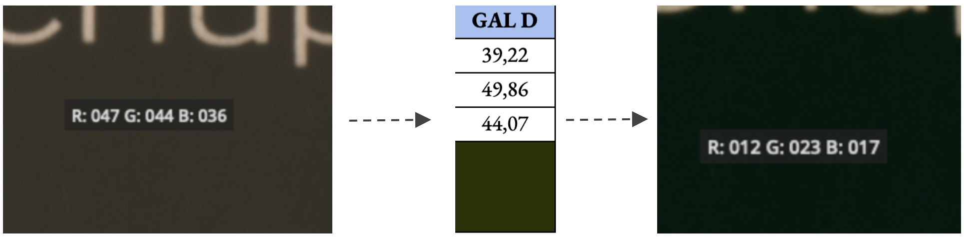


Fig.1 - Result of the color correction of the light parts (right) after matching the scanned image (left) to the RGB coordinates (center).

The last step was to match the dark parts to the measured RGB coordinates by regulating the RGB



channels individually, this time mainly for *Shadows*.

Fig.2 - Result of the color correction of the dark parts (right) after matching the scanned image (left) to the RGB coordinates (center).

The results and the method are experimental; however, the idea of using spectral measurements of the actual material, to try and maintain the characteristics even in the digital form, could be extremely useful to conduct more data-based and objective color corrections in film restoration.

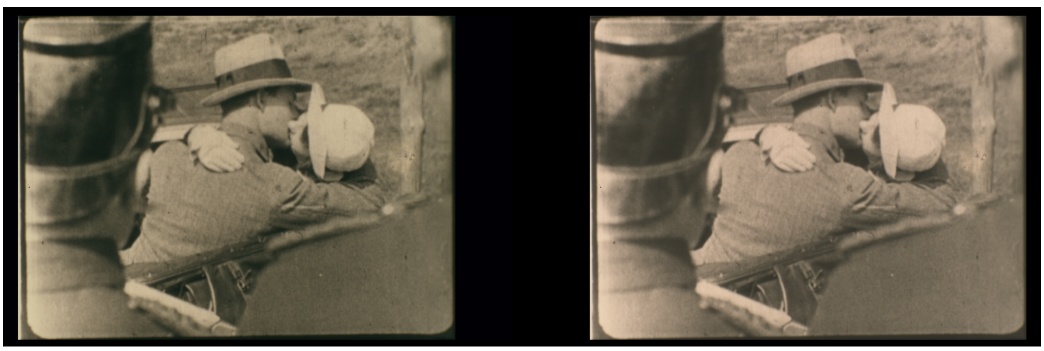


Fig 3. - After color correction (left) and before (right).

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Conclusions

Ozaphan films, produced from the late 1920s up to the 1950s in France and Germany, are among the less studied cinematographic materials. In this study we focused on the colors and tones analysis of these cellophane materials, first to document their spectrophotometric characteristics and second to assess how to preserve the films' color features digitally.

The spectrophotometric analysis, both in reflectance and transmittance, has been useful to assess the similarities, among materials of different ages and locations. Furthermore, the conversion into colorimetric coordinates allowed us to simulate Ozaphan-colors digitally and perform a data-based objective color correction.

In this context, it is important to remember the complexity of color perception, which cannot be simplified to a point-wise colorimetric conversion. Spectrophotometric and colorimetric measures should be used as a reference and be subject to the critical judgment of the restorer. As it was written in *A Material-Based Approach to the Digitization of Early Film Colours* we should not just use one «[…] single reference, but a multitude of references, or a field of references, that should be considered when we aim to emulate a film's appearance».

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Early Cinema: spectral and colorimetric analysis of Tinting dyes for film restoration

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Abstract

Early cinema is often mistakenly imagined as completely silent and colorless. However, in reality, movies were not only accompanied by live music and live dialogue but also had the presence of color. One of the Early Cinema's main coloring techniques was tinting, which allowed the coloring of entire frame sequences with dyes. The colors used in tinting had nothing to do with the natural colors of reality, as producers focused solely on their visual effect and the meaning conveyed in the scene's narrative. Therefore, restoring films from this period is extremely difficult because, when the film fades or deteriorates over time, it is almost impossible to restore the exact colors without reliable information or references from the originals.

In this work, we perform a spectral and colorimetric study of the Tinting dyes used in Early Cinema, starting from the literature. The aim is to establish a scientific base that can aid and support the cinematographic restoration of these films during digital color reproduction. First, we conducted historical and bibliographical research on the early 1900s cinematographic dyes. We traced the dyes and their official production methods for tinting through the various editions of Eastman Kodak's Tinting and Toning of Eastman Positive Films book from 1918 to 1927. We then searched for the UV-Vis spectra of these compounds, from which we computed a colorimetric analysis. The RGB values of each dye allowed us to create a colormap to digitally recreate the effect of tinting on a black-and-white image.

This preliminary study shows that spectral and colorimetric data could be useful to digitally recreate the colors of the Early Cinema faithfully to the original colorants. Further investigations must increase the number of dyes and deepen the spectroscopic research, as the spectra of the chemical compounds used in this study do not necessarily correspond to the concentrations specified in the original coloring preparation recipes.

Keywords: Tinting, film restoration, dyes, early cinema

Introduction

Attempts to replicate colors in films in order to make the scenes shot appear more "natural" have been made since the early days of cinema. This impetus motivated the cinematographic industry to develop techniques for film coloring since the early 900s, first by hand coloring or with stencil physical films and afterward inventing new, faster processes such as the tinting coloring technique (Read, 2009).

This latter method was based on the use of organic and inorganic dyes, which colored the whole frame through chemical reactions, establishing a link between the hues employed and the narrative elements of the film. Visually, tinted films appeared completely colored, not just on the frame with the film images but also on the side perforations. This is because the coloring was done by specialized film laboratories where the pre-printed film was immersed in shallow vessels containing one of the solutions of the various colorants. This allowed the colorization of a whole sequence in a short amount of time without risking damage to the film through excessive handling. Due to its ease of usage, this coloring technique remained popular until the 1920s; with approximately 80-90% of films from that era featuring partially or entirely colored frames using this approach (Read and Meyer, 2000; Read, 2009).

Unfortunately, despite the faster rates of colorization, the colors used had nothing to do with the natural colors of reality: the authors used them solely for their visual impact and the significance they added to the scene's narration (Fossati *et al.*, 2018). And it is precisely because of these colors

that restoring films from that early period of cinema is so challenging. When a film fades or deteriorates over time, restoring the original hues is very hard due to a lack of preserved information from the original copy.
For this reason, in this study we aim to digitally replicate the color provided by the most commonly used dyes with a scientific base beginning with the spectral and colorimetric research of these substances, in order to help the restorers achieve a more accurate color reproduction during the restoration of these films.

Historical and bibliographic research

The first step of this study is historical-bibliographic research in the literature on the main colors used in the period and their chemical composition. In order to improve the accuracy of the colorant's tint in digital tinting, we specifically looked for the processes used to create the color baths in which the films were submerged. The numerous editions of Eastman Kodak's 1918, 1922, and 1927 books "Tinting and Toning of the Eastman Positive Films" (Eastman Kodak Company, 1918, 1924, 1927) provided a wealth of information that allowed us to identify specific dyes and their authorized production methods for the Tinting coloring. The main dyes described and used by Eastman Kodak Company are summarized in Table 1.

Table 1 - Dyes for tinting described in Eastman Kodak Company books, 1918, 1924, 1927.

Dye's name	Modern name	Color	Manufacturer
Amaranth 40F	Amaranth	Red	National Aniline Chem. Co., New York
Azo Rubine	Azo Rubine/ Carmoisine	Red	White Tar Aniline Corp.56 Vesey St., New York
Crocein Scarlet MOO	Acid Red 73	Red	National Aniline & Chem. Co., New York.
Lake Scarlet R.	Acid Red 26	Red	National Aniline &Chem. Co., New York.
Wool Orange GG	Orange G	Red/orange	National Aniline & Chem. Co., New York.
Wool Yellow Extra Conc.	Acid Yellow 23 / Tartrazine	Yellow	National Aniline & Chem. Co., New York
Naphthol Green B Conc.	Naphthol Green B	Light green	White Tar Aniline Corp., 56 Vesey St., New York.
Acid Green L	Guinea Green B	Green	National Aniline &Chem. Co., New York
Niagara Sky Blue	Direct blue 15	Blue	National Aniline &Chem. Co., New York

According to the original recipes described in the manuals, in order to create the color baths, the solid colorants had to be dissolved in a minimum volume of hot water and then filtered through a muslin to ensure that all of the solid residues were thoroughly removed. This process was crucial to achieving a smooth and even distribution of color throughout the bath. Once the solid residues were completely eliminated, the solution had to be diluted in the tank to the volume specified by the recipe while maintaining a constant temperature of 18°C. When the color bath was ready, parts of the film or the whole film were immersed for a determined amount of time. Every dye described in the books was used to create a specific tint. Each tint, along with the respective dye and amount of water used to obtain it, is reported in Table 2.

Only a few of the mentioned dyes (those that are still used as colorants today) could be tracked. For the found compounds, we gathered their spectroscopic and chemical data.

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Table 2 - Tints described in the Eastman Kodak Company books, 1918, 1924, 1927.

Tint	Components	Avoirdupois (g)/(L)	Immersion time (min)
Cine Red	Amaranth 40F Water	1000 200	3
Cine Red	Azo Rubine Water	400 200	3
Cine Scarlet	Crocein Scarlet MOO Water	400 200	3
Cine Orange Red	Lake Scarlet R. Glacial Acetic Acid Water	200 0,1 200	3
Cine Orange	Wool Orange GG Glacial Acetic Acid Water	200 0,1 200	1
Cine Yellow	Wool Yellow Extra Conc Glacial Acetic Acid Water	400 0,1 200	1
Cine Light Green	Naphthol Green B Conc Water	800 200	3
Cine Green	Acid Green L Water	800 200	3
Cine Blue	Niagara Sky Blue Water	400 200	1

Colorimetric characterization of the dyes

After the identification of the tinting dyes of the Early Cinema, we focus on their colometric study. Lacking access to a chemical laboratory for recreating the recommended concentration of colorant solutions as described in reference materials, we found all the absorption spectra of the colorants we could find on the online spectral database *SpectraBase* (Wiley & Sons, 2023) available at the website *https://spectrabase.com* and other scientific paper (Souto, 2010; Yang *et al.*, 2018; Leulescu *et al.*, 2021; Vannucci *et al.*, 2021).

We relied our colorimetric analysis upon these spectra, focusing on the wavelengths in the range of the visible spectrum (380–780 nm). First, we transformed the spectra from absorption SPD_A to transmittance SPD_T following the formula derived from the Lambert-Beer law:

$$\mathrm{SPD}_T = 10^{(-\mathrm{SPD}_A)} \quad (1)$$

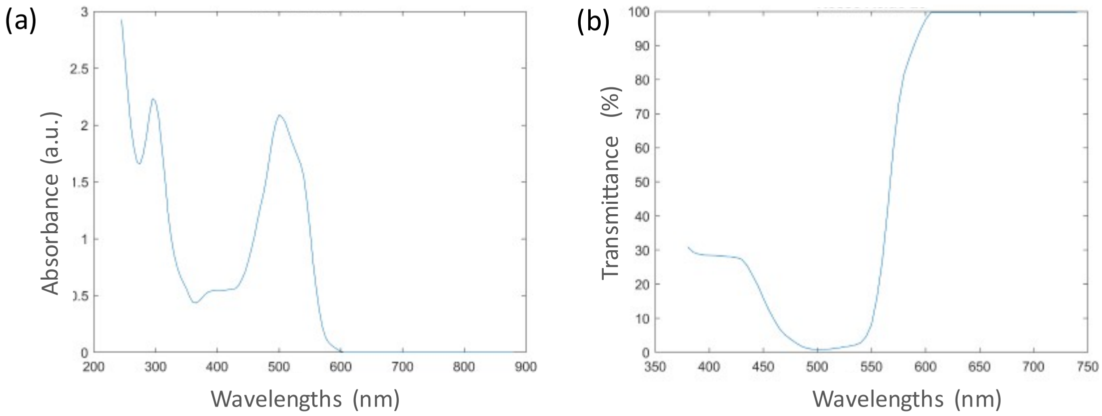

Figure 1. - Absorbance spectrum (a) and Transmittance spectrum (b) of *Acid Red 26* (Vannucci *et al.*, 2021).

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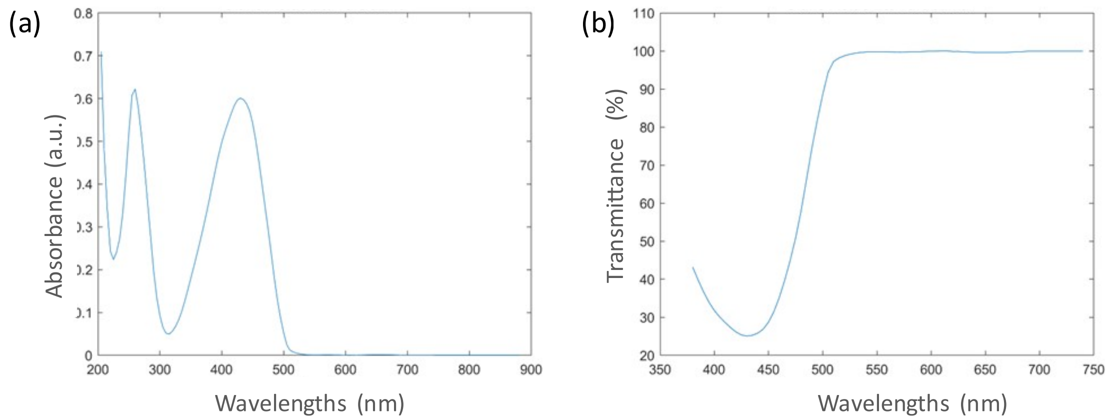

Figure 2. - Absorbance spectrum (a) and Transmittance spectrum (b) of *Acid Yellow 23* (SpectraBase, 2023).

Figure 1 and Figure 2 show two examples of spectra transformation for the colorants Acid Yellow 23 and Acid Red 26 respectively. In Figure 3, we have grouped all the transmittance spectra of each tint found in the Kodak books that are still used today as colorants.

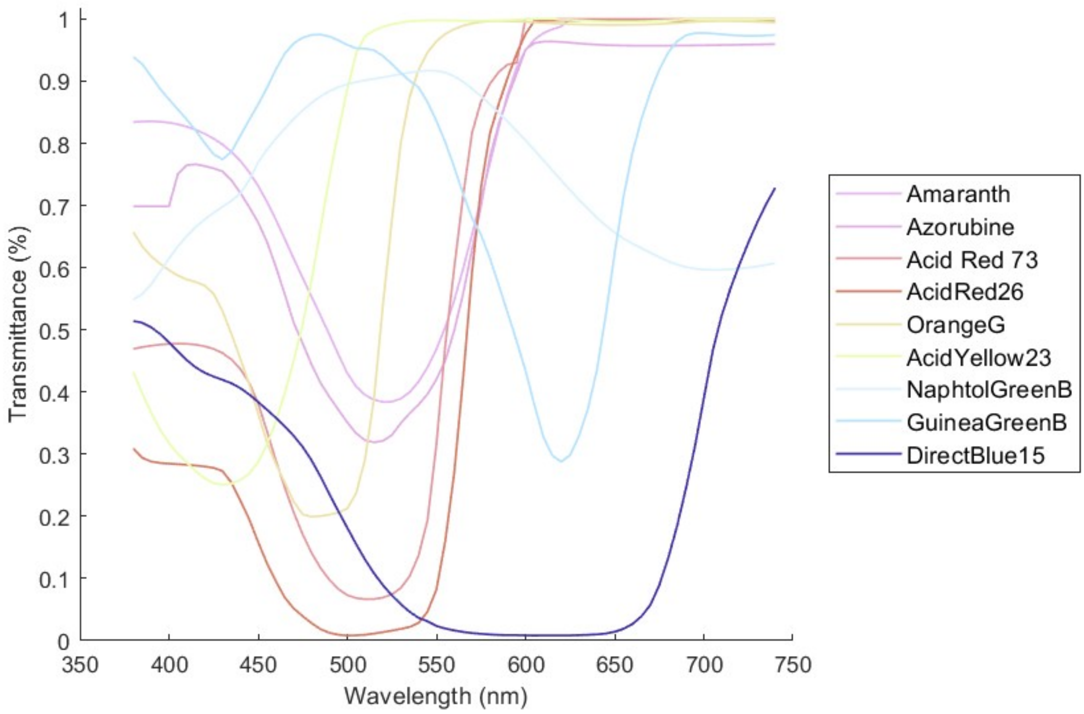

Figure 3. - Transmittance spectra of each tint found in (Eastman Kodak Company, 1918, 1924, 1927).

From the spectra, following the CIE guidelines (CIE TC 1-85, 2018) we then calculated the tristimulus values CIE XYZ, the chromaticity coordinates CIE xy and the RGB values of the colorimetric space sRGB, Adobe and Pro Photo, the most common RGB spaces. Table 3 reported coordinates XYZ and xy, while Table 4 summarizes the corresponding RGB values.
Several coordinates lie out of the gamut boundaries of all three color spaces (values reported in red in Table 3), especially for sRGB. As only a limited subset of ProPhoto RGB values falls beyond the gamut, we used the coordinates of this color space for the digital color reproduction. Out-of-gamut values were projected onto the surface of the color space constraining to 25 any values exceeding this threshold.

Table 3. - XYZ and xy coordinates of the dyes under analysis in the range [0,1].

Dyes	X	Y	Z	x	y
Amaranth	0.759	0.618	0.745	0.358	0.291
Azo Rubine/ Carmoisine	0.729	0.579	0.668	0.369	0.293
Acid Red 73	0.706	0.508	0.347	0.452	0.325
Acid Red 26	0.614	0.395	0.154	0.528	0.340
Orange G	0.823	0.825	0.391	0.404	0.405
Acid Yellow 23 / Tartrazine	0.829	0.965	0.424	0.374	0.435
Naphthol Green B	0.763	0.867	0.851	0.308	0.349
Guinea Green B	0.581	0.736	0.960	0.255	0.323
Direct blue 15	0.081	0.055	0.388	0.154	0.104

Table 4. – sRGB, Adobe RGB and ProPhoto RGB coordinates of the dyes under analysis. In red are the values out of the range (0,255)

Dyes	sRGB			Adobe RGB			ProPhoto RGB		
	R	G	B	R	G	B	R	G	B
Amaranth	270	180	218	248	178	216	229	180	241
Azo Rubine/ Carmoisine	270	171	208	247	169	205	225	172	227
Acid Red 73	289	145	149	259	144	148	226	151	158
Acid Red 26	286	109	96	252	109	96	212	122	100
Orange G	277	227	147	264	226	150	237	226	168
Acid Yellow 23 / Tartrazine	254	258	148	255	258	154	233	257	176
Naphthol Green B	220	246	227	227	246	227	219	242	259
Guinea Green B	143	238	243	176	238	243	182	227	277
Direct blue 15	-34	57	170	6	59	166	60	46	168

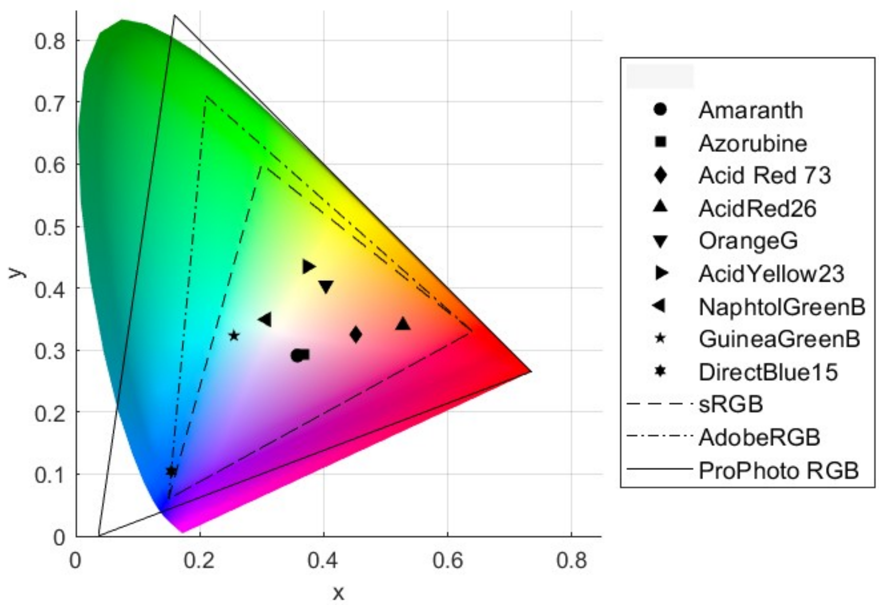

Figure 4. - Colorant’s x, y values in Chromaticity Diagram with RGB spaces

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Digital tinting reproduction

To mimic early cinema tinting on a digital frame, we developed colormaps based on the RGB values of each dye as schematized in Figure 5. Since ProPhoto RGB has a wider gamut (see Figure 4), we worked in this color space. All the computations were done using Matlab. To include all the shades of a tint we selected all the colors lying on the line parallel to the Black-to-White major diagonal of the RGB color space (blue line) and passing through the coordinates of the chosen dye (black dot). All the colors out of the gamut were reported to the RGB cube surface (thus clipping to 0 the values below 0 and to 1 the values above 1) obtaining the orange line of Figure 6.

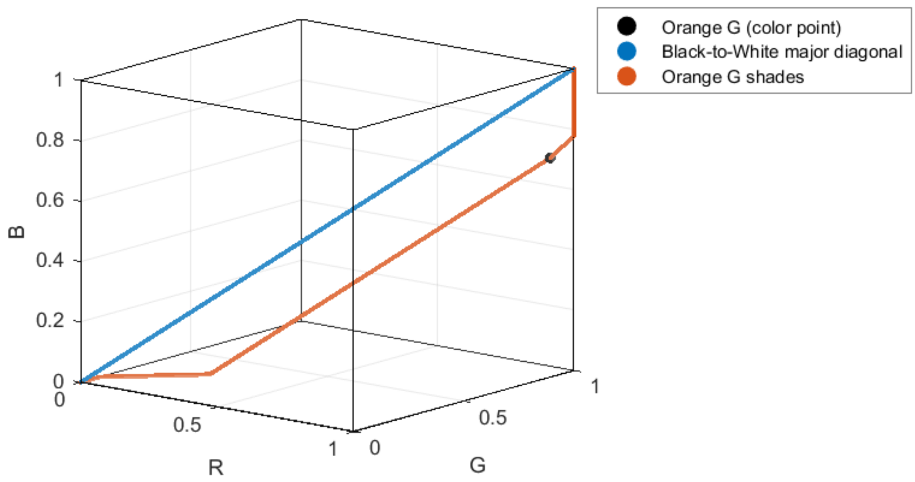

Figure 5. - Graphical representation of the method used.

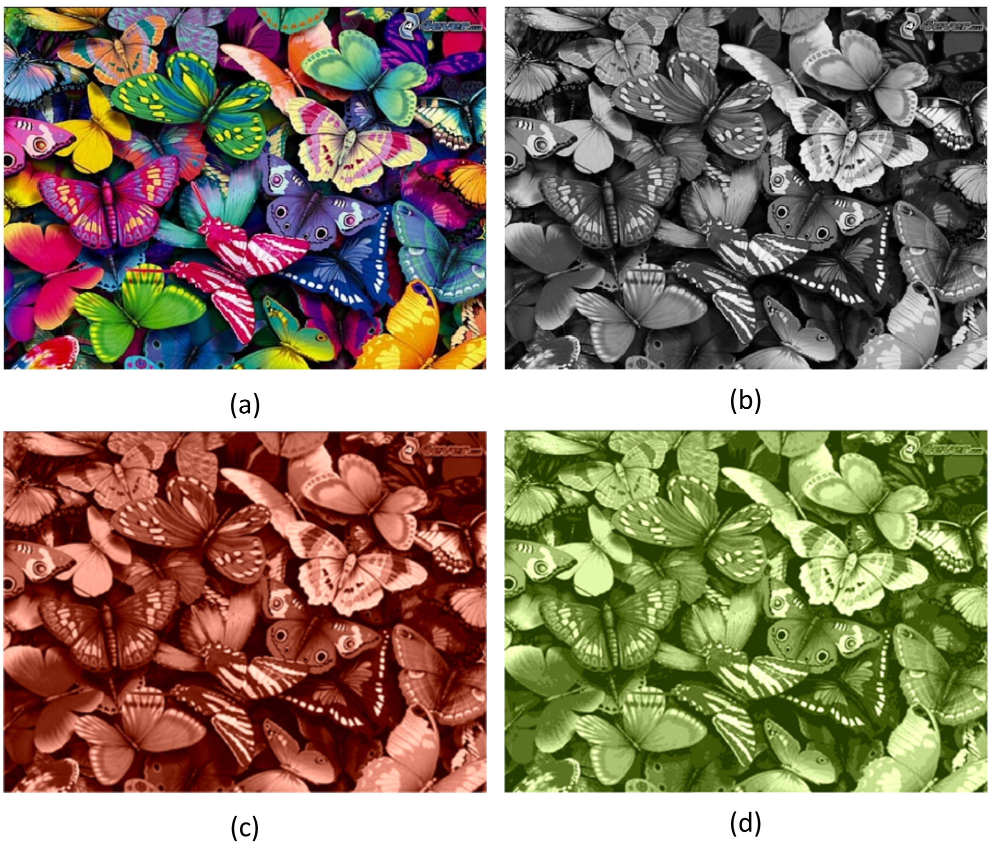

Figure 6. - (a) Original natural image; (b) image in grey scale; (c) image tinted with Acid red 26; (d) image tinted with Acid Yellow 23.

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Better outcomes can be obtained by employing reflectance spectra that match the precise concentrations listed by Kodak. The spectra presented in this article did not exactly match the concentrations because our initial goal was to determine whether the method could be used. In reality, these spectra produced color simulations that were either more or less intense than they really had to be. A better and more realistic simulation of color tones can be achieved by measuring the reflectance spectra of several chemicals at various known concentrations.

Conclusion

In this paper, we have investigated a method to replicate the dyes used by Kodak in the tinting process of Early Cinema films. After bibliographical research and a colorimetric analysis of the dyes found in the literature, we digitally replicated the tints and then colored black-and-white images to simulate a frame restoration, proving that the method we used is valid. Whit these are preliminary results, we aim to establish a scientific foundation to assist restorers and experts in the field in achieving a more objective and faithful restoration, aligned with the historically employed materials and dyes. Further study would investigate a broader range of dyes, from other companies that Kodak and used outside the United States.

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