Color Culture and Science
Cultura e Scienza del Colore

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

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

Second review level
Two or three experts review each article with a blind peer-review process where the reviewers are kept anonymous. Reviewers are asked to evaluate the manuscript based on the following criteria:
– Originality
– Relevance to journal's aims and scope
– Technical merit and/or validity
– Soundness of methodology
– Completeness of the reported work
– Conclusions supported by the data
– Correct acknowledgment of the work of others through reference
– Effectiveness of the manuscript (organization and writing)
– Clarity of tables, graphs, and illustrations
– Importance to color researchers
– Relevance to color practices

If the article is accepted with major revisions, the author(s) are asked to improve the article according to the reviewers' suggestions. The revised article will then be submitted for further review.
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TOPICS
The CCSJ accept papers on a wide range of topics on color, including and not limited to the following:
1. Color and Measurement/Instrumentation. Colorimetry, photometry and color atlas: method, theory and instrumentation; quality control and food coloring, dyes, organic and sustainable color.
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3. Color and Lighting. Metamerism, color rendering, adaptation, color constancy, appearance, illusions, color memory and perception, color in extra-atmospheric environments, lighting design, lighting technologies, visual comfort.
4. Color and Physiology. Mechanisms of vision in their experimental and theoretical aspects, color vision and color appearance, deficiencies, abnormalities, clinical and biological aspects, synesthesia, health, well-being.
5. Color and Psychology. Phenomenology of colors, color harmonies, color & form, perceptive, emotional, aesthetic, and diagnostic aspects.
6. Color and Production. Food and beverages, agriculture, textiles, plastic materials, ceramics, paints, gemology, color in the food industry.
7. Color and Restoration. Archaeometry, painting materials, diagnostics, and conservation techniques, restoration, and enhancement of cultural heritage.
8. Color and Environment. Representation and drawing, urban planning, the project of color, architecture, interior design, landscapes & horticulture, color and architectural syntax, territorial identities, biodiversity.
9. Color and Design. Furniture, CMF design, fashion, textiles, textures, cosmetics, food design, museography.
10. Color and Culture. Arts and crafts, history, philosophy, aesthetics, ethno-anthropology, graffiti, geology, sociology, lexicology, semantics, anthropology of vision, food culture and heritage, color naming.
11. Color and Education. Pedagogy, didactics of color, aesthetic education, artistic education.
12. Color and Communication/Marketing. Graphics, communication, packaging, lettering, exposure, advertising.

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Editorial

As our readers know, this journal is published by Associazione Italiana Colore. The fact that it is diamond open means that it is free even for authors. This is a distinctive element of its publisher, a non-profit association, which stands in contrast with the many science predators present worldwide today. It is worth mentioning that in September 2021, the Associazione Italiana Colore organized the AIC2021 14th Congress pursuing the same ethical principles.

The International Color Association (AIC) Congress is a unique multidisciplinary event that brings together scholars and professionals from various fields. It has been held every four years since its inception in 1969. In 2021, it was hosted in Italy, for the first time, organized by the Associazione Italiana Colore. The Covid19 pandemic imposes multiple constraints all over the world. In Italy, the state's laws and the safety rules of the previously chosen Venue (Ca' Granda, Università degli Studi di Milano) prohibited any socializing, which is one of the fundamental reasons for the participation in presence. Moreover, due to travel-related risks and restrictions, the Associazione Italiana Colore, in agreement with the AIC, has decided to organize the AIC 14th Congress online in compliance with the program elements required by the AIC rules: Opening Ceremony, Awards, AIC General Assembly, AIC Study Groups Workshops and Closing Ceremony.

In AIC2021, which should have been in presence, we wanted to create an Ethically Sustainable Congress, thinking about young people, retired people, and professionals who cannot afford to spend too much to attend a Congress. This was our leading idea since 2016 when we proposed Italy to AIC EC in Santiago. Following this idea, the early registration fee available since 2020 for the 14th AIC Congress was about half that of the previous Congress. On January 5th, 2021, in agreement with the AIC, it was decided that, due to Covid19, the AIC 14th Congress should be held online. Therefore, it has agreed to halve further the early registration fee, which is less than a quarter of the previous Congress, lower than the fee of students and the single-day fee of the previous congresses. With a fee equivalent to what used to be the registration of a single day, now participants could follow in the entire five-day Congress. To achieve this goal, the AIC2021 Congress is organized and directly administered by Associazione Italiana Colore, a non-profit association. Associazione Italiana Colore could have decided to delegate the organization and administration of the Congress to a company specialized in the organization of events, but this would have more than doubled the current registration fee even for an Online congress and would also have added VAT (+ 22% in Italy). For a 5-day online Congress, this would have resulted in doubling the registration fee. This has been possible thanks to the volunteer work of the members of the Associazione Italiana Colore in the organizing committee, which I want to acknowledge and thank.

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Zhang Yimou: great master of color

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ABSTRACT

As a pioneer of Chinese cinema, Zhang Yimou, has directed a number of films spanning various historical periods, genres and techniques, but if there is a style or technique that really defines him, this is the skillful, symbolic and communicative use of color. Many critics claim that red is the color that voluntarily characterizes his films, but he himself tells how this distinctive preference of his first films was due to the environment in which he grew up in Northern China, in which red for centuries has not only been the bearer of meanings, but also a cultural heritage, a representative sign of a past to be rediscovered and preserved. In fact, many aspects of the culture of this great country converge in red and in the term that translates it, so much so as to be a metaphor for customs, traditions and feelings. In this research we have tried to go beyond this cliché by taking into consideration the whole of his film production. We analyzed five films: two wuxia (a narrative genre, typical of Chinese cinema, which mixes martial arts with fantastic and adventurous elements), the first Hero (2002), where the color of the clothes, draperies and sets changes according to the unfolding of the story and the last, Shadow (2018), in which the color belongs directly to the set design and costumes, and which brings us back to the black and white painting that inspired generations of Chinese writers. Then we analyzed three other historical-social films, Red Sorghum (1987), Ju Dou (1990) and Raise the Red Lantern (1991) which represent Chinese society in the 1920s and 1930s. In the analysis of these films we have been able to identify three different ways of using color: one narrative, one symbolic and one that we can define as historical-aesthetic.

KEYWORDS China, cinema, communication, art

1. Introduction

Zhang Yimou director, screenwriter and cinematographer of many of his movies is perhaps the most important director in contemporary China. His training passed through *Mao*'s cultural revolution, which saw him working first in the countryside and then in a textile company, to arrive, after *Deng Xiaoping*'s reform, at the Beijing Film Academy in the photography department. After collaborating with several directors as camera operator, set photographer and actor, he made his directorial debut with the movie *Red Sorghum* (1987) and became part of that large group of filmmakers defined as fifth generation.

As a pioneer of Chinese movie making, he has directed a multitude of films spanning various historical periods and genres, but if there is one style or technique that defines him, which connotes his works and is part of his poetic journey, it is the particular artistic, symbolic and communicative use of color: a tool that has always been used in traditional Chinese theater to communicate situations, personalities, feelings, both in the courtly and popular culture, as well as in communist China with new meanings and new representations.

A paradigmatic example and covered in every aspect in many of *Zhang Yimou* 's movies is the red color: in the past a precious dye obtained from cinnabar and since the time of the Song dynasties used to color the seals placed by the literati on painting and calligraphy works. Later it was the color of the revolution, of the red flags, of the little red book, and last but not least of the 'red sun', which is still the symbol of Mao.

We like to think that the director uses it to sign, as if with a seal, many of his works, even if he himself says that this color is simply that of the traditional culture in which he was born, a cultural heritage of northern China where he grew up and a representative sign of a past to be rediscovered and preserved.

In this research we have considered the three movies with a social-historical character *(Red Sorghum 1987, Ju Dou 1990, Red Lanterns 1991*) that tell the story of China in the 1920s and 1930s and two wuxia[1] films, the first and the last: Hero (2002) and Shadow (2018). Looking at the work as a whole, we identified three different ways of using color: symbolic, narrative and aesthetic.

2. The symbolic color

Many commentators claim that red is the hallmark of *Zhang Yimou*'s movies. In the works we have chosen to see and that describe a period that takes into consideration the 1920s and 1930s of Chinese history,

red is indeed one of the main protagonists. In red we find a symbolic and communicative complexity linked to the millennial history of this country, a history that is part of the tradition, beliefs and collective imagination. We have analyzed the various aspects of red in three movies, two of which also carry this color in their titles: *Red Sorghum, Jou Dou, and Red Lanterns*.

These three movies are known to critics as the "Red Trilogy, both because they share the predominant use of this color in a palette reminiscent of that of ancient China where red and yellow and gray dominated imperial and popular culture, and because of a common concern for national identity, political engagement, and the human and natural landscape.

"The dominant red of these movies has a double significant value: if for the Western audience it becomes the main stylistic feature of the author... for the Chinese it constitutes the occasion to recover, perhaps unconsciously, a heritage of symbols originally present in their own culture but later lost" (Colamartino and Dalla Gassa, 2003)and the reds illuminate the screen, capturing the attention in the traditional silk dress of the Chinese bride, draped inside the sedan while the conjugal procession crosses the fields, in Red Sorghum; they become dramatic in Ju Dou where, in the dyehouse, strokes of fabric from yellow to red unfold before the eyes of the spectator like strokes of paint on a canvas; and they permeate every scene of Red Lanterns, lighting up on the gray of the courtyard and becoming claustrophobic in the interiors.

2.1 Red Sorghum (1988)

"*Red Sorghum* is one of the most important movies of the Fifth Generation for several reasons: it is the first Chinese film to win a prestigious award, the Golden Bear in Berlin in 1988." (Colamartino and Dalla Gassa, 2003). It tells the story of the young and beautiful *Nine Flowers* sold as a bride to the old leper, owner of a red sorghum distillery and her love affair with the young *Yu*, whom she marries after the death of her husband and with whom she has a son; the plot takes place against the backdrop of the Japanese invasion of the '30s and will see *Nine Flowers* heroically fight for her country and die. Red, the color that speaks of the immutability of the spirit and of Chinese tradition, marks the opening scene of the film where the young bride is seated in a sedan chair covered with a fluttering fabric of this color and marks the end, where a solar eclipse accentuates the tragic dimension and red spreads across the screen.
In the initial phases, intense red is used in the traditional sense, as a color linked to marriage, luck, love and wealth: red is the sedan chair, red is the dress of *Nine Flowers*, an intense red that occupies the scenes of the

wedding, wanting to hide the unhappiness of the bride and capturing the attention and the gaze of the viewer. A red that runs through the tragedy of the sold woman and with which Zhang Yimou launches the social denunciation of a period that the revolution has now left behind. Behind this color lies the tragic fate of many women anchored to the customs of a feudal society where red, from a symbol of love and happiness, became a sign of male power.

In this color, so rich in shades and meanings, tragedy, violence, sin and war also unfold: when Japanese troops invade China, including the village where *Nine Flowers* lives, she will organize the resistance, dying for the freedom of her country in an apotheosis of warm and dramatic orange and red tones.

In this movie the symbolism of red is clear: on the one hand it underlines revolutionary commitment and on the other hand passion and love. By presenting itself in a recurring way - dress, liquor, fire, blood - it captures and guides the attention of the spectator.

2.2 Ju Dou

Also in this movie, the director denounces the medieval custom of buying wives. Ju Dou is the wife bought by Jinshan, an old and impotent dyer, and she engages in a romance with Tianqing, a nephew of her master who works as an apprentice in the dye shop and with whom she has a son. The movie is set in a rural textile mill.

Throughout the movie, *Ju Dou* and *Tianqing* are oppressed by *Jinshan* 's tyrannical, suffocating, and vigilant behavior, and even after his death, *Ju Dou* and *Tianqing* cannot live as they wish because they struggle to appease cultural expectations and hide their illicit relationship. The movie ends in an extremely dramatic way: *Tianqing* is murdered by their own son and *Ju Dou* kills herself by burning the mill around her.

In this movie red recalls its very archetypes: blood and fire. With blood it shares the sense of life in the most intense and transgressive parts of sex and death, with fire that of purification and destruction. It is the red dye poured into the dyeing tub that heralds the final drama of the death of two of the male performers pushed and drowned in that tub, one almost by accident and the other by revenge; both *Ju Dou* 's husband and her lover lose their lives in this colored water. It is a red that marks loss: loss of purity during the sex scenes, loss of honor, loss of husband and lover, loss of the murderous son, and marks the unfolding of the drama by accompanying the viewer, as in *Red Sorghum*, in the red light of the expiatory fire.

Once again, color becomes a fundamental element of the story, underlining its emotional phases: from purple red to golden yellow in the clandestine relationship, turning into dark and livid tones in the tragic finale, a single color presented in different shades to portray passion, jealousy, revenge and 'crime'.

2.3 Red Lanterns (1991)

In this movie, the last of the trilogy, which earned Zhang Yimou the Silver Lion at Cannes, the director once again puts the Eastern patriarchal order under indictment. The setting is pre-revolutionary China, and the theme is the relationship between sexes.

The story takes place in the 1920s and is about the young and beautiful *Songlian* who is forced to abandon her studies due to the death of her father and marry *Chen*, a rich landowner who already has three wives. The plot takes place inside the gray and cold courtyard on which the doors of the rooms of the concubines and that of the owner open. The only colorful element is the red of the lanterns that are lit near the door of the concubine with whom the man decides to spend the night. The women compete for exclusivity over the husband and a fierce rivalry arises that results in a bitter ending.(Moviestruckers, 2017). *Songlian*, in order to gain her husband's favor, lies about being pregnant and when she is discovered, after a series of dramas, she goes crazy. The lighting of the lanterns is a sign of status for the concubines because whoever wins her husband's favor receives an elaborate foot massage and the right to decide the menu for the entire family the following day. It is therefore the red of the lit lanterns or the black of the drapes that cover them to mark the moments of the tragedy, and it is always a radiant red light, diffused in the rooms together with the furnishings and the clothes of this color to mark the desire, the love and the tragic destiny of the protagonist, a red symbol of wealth, dominion, power, sex that in the denunciation becomes also a symbol of oppression.

2.4 Red in the trilogy

In these three movies, red defies any narrow interpretation, because it indicates both a rejection of tradition and its heritage. It is no longer a celebratory color as in ancient China or revolutionary as in modern China, it could be described as a state of mind, as a feeling. As *Zhang Yimou* once said, "We Chinese have been too moderate, too reserved... the boundless red of sorghum fields arouses sensory excitement... it encourages the joy of living." (Gateward, 2001).

In his movies, red becomes the primary color of life and in the course of the events of the trilogy it becomes a commemoration of freedom, exuberance and the most primitive and natural desires and aspirations.

3. Narrative color: Hero (2002)

Hero is the first wuxia film made by Zhang Yimou in 2002. The story takes place in China in the historical period called 'of the Fighting Kingdoms'. Indeed, the Chinese territory was divided into seven kingdoms that fought for supremacy, the most powerful of which was the kingdom of Qin. The plot, simple and complex at the same time, is based on the true story of Jing Ke (Nameless) a swordsman who prepared for ten years to kill the king of Qin (227 BC).

In the movie Jing Ke is *Nameless,* an unknown swordsman who one day presents himself to the king of Qin saying that he has succeeded in killing all those who plotted against his life.

Nameless refers to *Sky*, an assassin, unbeatable with a spear, to *Flying Snow*, a woman and a skilled swordsman whose family was exterminated by the king, and to her lover *Broken Sword*, an extraordinary master both in swordsmanship and in the art of calligraphy. However, during the story, the king realizes that *Nameless* is deceiving him and that this was a way to get close to him and kill him.

The complexity comes from the director's choice to narrate the events seen from different angles with different levels of truth, so that the audience can learn about facts and characters from different standpoints. A choice made by other directors before him, such as Quentin Tarantino and Akiro Kurosawa, but what makes this choice different, unusual and original is the use of color. Indeed, it is the color of the scenes, of the clothes, of the furnishings, in which the characters act that marks the unfolding of the narration in a discontinuous continuity that leads from deception to truth.

The story relies on flashbacks, wonderful pieces of dazzling colors that involve the viewers and guide them into the complexity and ambiguity of the events. Black, red, blue, white and green are the five colors chosen by the director to mark the timings and to identify with immediacy the direction of the story: colors that also involuntarily expand their allegorical dimension and influence the perception of time that in the red seems to flow faster, while in the blue, despite the action, it becomes slower and contemplative.

The author, in the interviews following the film's release, excluded that he wanted to use color in its symbolic dimension and that he had given it more simply the task of separating and unifying the story in an immediate, easy, safe and aesthetically involving way, so as to guide the spectator across the film's complex plot. In reality, given the intrinsic characteristic of color to express universal meanings and emotions deriving from its archetype, we can observe how the chromatic alternations are in harmony with the contents of the story. Different colors to represent the inner worlds and situations of the different characters. Because in *Hero* there is everything: love, hate, revenge, resentment, art, gracefulness, elegance and violence.

Black is the color that marks the beginning. Black are the palace, the garments of *Nameless*, the soldiers' armor, the king's dress; a black emphasized by the fixity of the image with the main character at the center of the scene. And black concludes the movie, a hard, contracted black that promotes an aesthetic of cold-blooded, fearless death. Between these two blacks the colors of the story unfold.

Red marks jealousy, betrayal, revenge, love and passion, and pride among the fighters that unleashes a centrifugal force underscored by the flight of leaves and flying sand that permeates the scene. It is the fire of jealousy that will bring death to the swordsmen.
The blue following the red shows us the story as seen from a different angle. In this color it is the outdoor space that dominates the action and gives the scene a sense of calmness and serenity emphasized by the camera that slowly follows the movements of the swordsmen and emphasizes the lightness of their clothes and the air.

White, color of mourning, death, but also of purity wants to assert the actual innocence of the swordsmen: in ancient times in China it was thought that a change of dynasty was not a mistake, but it was necessary when an emperor did not rule according to the Confucian rules of good governance. In this way, the end of a dynasty preluded to a new and better life for the empire.

When the story is colored with green, the feeling is that this color is the most suitable to describe the feeling of peace and joy that breathes in the hearts of the second and third swordsmen. In addition to marking the final change in the story, this shade of green reminiscent of jade, for the Chinese since ancient times a rare material with esoteric virtues, symbolically reveals victory over death. Nameless dies, but he will be given the solemn funeral that is usually arranged for heroes: the promise and guarantee of a long life in the memory.

4. Aesthetic color: Shadow (2018)

Based on the *Novel of the Three Kingdoms*, a classic of Chinese literature, *Shadow* tells the story of an ambitious king determined to regain a part of the kingdom and his great general, Commander *Zi Yu*, a visionary man driven by the desire to win, but forced, since he lacks the strength, to use a double to fight in his place: his shadow,

a peasant who resembles the commander and replaces him when necessary and with whom he also shares his wife, but not the nuptial bed. Both characters are played by *Deng Chao*. The plot is complex, full of intrigue and references, dominated by the sign and metaphor of yin and yang, the two opposing principles that involve, in addition to motion and stillness, a long series of contrasting elements: light and darkness, hot and cold, expansion and cohesion, evolution and involution, activity and rest, life and death, male and female (Luzzatto, 2019)whose image is proposed in more than one occasion to narrate the light and "shadows" of the protagonists.

"The main theme is that of the double: the original and its shadow, the true and the false, but also the masculine and the feminine. A game of pairs that is extraordinarily marked on a chromatic level by black and white, with the photography of *Zhao Xiaoding* that almost exclusively uses shades of gray"(Balsamo, 2018). The story unfolds in the beginning in a measured and dare I say guarded way to then accelerate with dramatic contours in the final in a claustrophobic landscape where rain continues to pour down. We are a long way from the masterful colors of *Hero*: the fiery reds, the tranquil blues, the purifying whites... In this movie the palette uses the many shades of gray between a sometimes dazzling white and a deep black, turning also to 'colored grays', those shades that carry the memory of a hue. After the first scenes, the colors sneak in, they are those of the skin, the dark red of blood, the memory of the green of the vegetation... the characters live, plot, attack, defend themselves and die, in incredible varieties of a sometimes unnerving gray - a choice that the director claims to have been inspired by Chinese brush painting, the one that *Shitao*, a painter and poet who lived during the *Qing* dynasty (1642/1707), wrote about: "The one stroke carries within the totality of beings. The stroke receives the ink, the ink receives the brush, the brush receives the pulse, the pulse receives the spirit." (Shitao, 2008) (Luzzatto, 2019 page 77). A monochrome painting obtained from the dilution of black ink, by which generations of artists-literates have been inspired, submitting themselves to a strenuous spiritual exercise aimed at recreating the cosmic and natural order where "everything is in relation and where the One, the void, the creative power that contains everything, becomes Two originating the pair Yin (black) and Yang (white): the opposite and complementary movements that enable every form of life and according to which reality is expresses itself" (Luzzatto, 2019).

So in this work of his maturity *Zhang Yimou*, who has always looked to the aesthetic-symbolic tradition of his country, deeply anchored in its ancient history and in the Confucian and Daoist tradition, tried his hand at the artistic tradition deriving from Buddhism, painting the scenes with a meticulous and monochromatic choice of places, environments and furnishings and with masterful framing, camera movements and photography. The *yin/yang* symbol often appears on the ground during filming and refers to its philosophical complexity: it is a fighting arena for the commander and his shadow, it is the preparation of the shadow that, in order to train for the fight, takes possession of the feminine side of his lover, making his own the axiom that nothing can be completely *yin* or completely *yang* because both contain the seed of their opposite. There are many references, especially in the landscape, to the scrolls of the ancient masters with the contours of the hills that emerge from the mist, the pouring rain and the dark tones of a gray that turns to black sometimes emerging from an intense white, like ink on white paper. The feeling is that the events take place in a darkness that from the rainy exterior spreads to the interior like an immense shadow. The eye gets lost in the formal and chromatic refinement, which is not absence, but reduction and follows the unfolding of the representation as in the ancient paintings painted on vertical scrolls that were hung on the wall and whose vision was accomplished slowly in their unfolding, as a succession of images on the screen.

For a general discussion of the topics covered in this article (Zehou, 2004).

5. Conflict of interest declaration

The authors declare that nothing affected their objectivity or independence and original work. Therefore, no conflict of interest exists.

6. Funding

7. Authors Short Biography

Lia Luzzatto
Essayist, publicist and chromatic consultant. Professor of Color Theory in university faculties, she participates and organizes seminars and courses in Italy and abroad. She is the author of numerous historical and educational books on color, an interest that she started from the lessons of Luigi Veronesi at the Brera Academy of Fine Arts.

Laura Del Zoppo

Graduated from the Brera Academy of Fine Arts, she is a director and art director. She has made numerous broadcasts and commercials for various television networks. She has had teaching positions in several private academies in the history of contemporary art and fashion show production courses.

Notes

[1] With wuxia we mean a narrative genre, typical of Chinese cinema, which mixes martial arts with fantastic and adventurous elements.

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A didactics of colour based on an innovative educational approach at the Hochschule für Gestaltung in Ulm

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Abstract

Tomás Maldonado held the posts of lecturer and rector at the famous Hochschule für Gestaltung in Ulm from 1954 until 1967-68. His foundational contribution to the field of education/training dates to his thirteen years at this school, where he concentrated his theoretical and practical inquiry on developing a new approach to the teaching of key design-related subjects.

While at Ulm, Maldonado became keenly interested in devising an innovative new teaching method based on the notion of "cooperation among disciplines".

This principle guided him throughout his lengthy teaching career, as he enriched and refined his educational thinking and developed increasingly effective teaching methods for the disciplines he taught. There was something important and revolutionary about his teaching approach and his method also became well known in Italy. Even earlier, as a very young artist in Argentina, where he helped to found the Concrete Art movement, he had displayed and constantly shared with others an "almost obsessive preoccupation" as he himself defined it, with actively contributing to a total vision of culture. Towards the end of his life, he characterized this project as "over-ambitious". However, it showed that he was interested in cross-disciplinarity from the outset. Crossdisciplinarity, or the "third culture", as he himself called it and understood as the attempt to overcome the dichotomy between "hard" and "soft" sciences. In light of this background, I set out here to examine Tomás Maldonado's approach to developing new teaching methods for his classes, especially in relation to the theme of colour as an integral part of his course in Visual Methods.

1. Introduction

Tomás Maldonado held positions as a lecturer, and later rector, at the famous Hochschule für Gestaltung in Ulm (Germany) between 1954 and 1967-68.

In this paper, I offer an analysis - based on my personal acquaintance with Tomás Maldonado and my knowledge of his studies and his works - of his teaching methods and especially the "didactics of colour" that he devised for his course in visual methods. I was stimulated to document his teaching of (and with) colour by our shared interest in certain themes. One interest that we had in common was a passion for colour and how it is perceived, topics that we often discussed, and which for Maldonado were the object of meticulous study, enriched by his wideranging inquiry into the culture and science of colour. Here, I document some extraordinary interdisciplinary and transdisciplinary exercises he designed and implemented with his students during his years on the academic staff of the foundation course in design at the Hochschule für Gestaltung in Ulm.

His interest in teaching and training, which he later continued to pursue in other universities around the world, first developed during his time in Ulm.

Over these thirteen years, Maldonado focused his theoretical and practical inquiry on developing a new perspective on teaching particular subjects, both to students of design and to those pursuing other branches of study.

2. Who was Tomás Maldonado?

"[...] Although I was not very young when I arrived in Ulm, I was thirty-two and [had previously enjoyed] a short but intense career as an artist in Argentina, I acknowledge that the [Ulm] experience played a decisive part in my formation.

It contributed to considerably broadening my intellectual horizons… I am especially alluding here to my theoretical (and practical) engagement with industrial design and communications.

At the same time, it was in this very setting that I developed an interest in semiotics, the philosophy of science and technology and, last but not least, the sociology of communications.

A crucial role in all of this was played by the educational challenge, the need to prove myself every day in my teaching.

Suddenly I discovered within myself a passion that would remain a constant throughout the rest of my life; a passion for making myself useful in the intellectual (and professional) training of young people. […]" (Maldonado 2010, p. 29)

Tomás Maldonado arrived in Ulm in 1954 at the invitation of Max Bill, a well-known exponent of the Concrete Art Movement in Switzerland. The academic staff at the German design school was composed of internationally recognized figures from all over the world.

During his years at the Ulm school, Maldonado was appointed Lethaby Lecturer at the Royal College of Arts in London in 1965, Fellow of the Council of Humanities at Princeton University in 1966 and lecturer at Princeton's School of Architecture from 1968 to 1970. In 1979, he was research fellow at the Graduate School of Design at Harvard University and gave numerous lectures at other universities in the United States and around the world. In the 1970s, he moved to Italy; first to the University of Bologna from 1971 to 1984, where he taught on the degree course in Music and the Performing Arts offered by the Arts and Philosophy Faculty, and subsequently at Milano Politecnico, where he was based at the Faculty of Architecture from 1985 to 1997 and taught on the degree course in Industrial Design he himself set up in 1993. He also taught at the Faculty of Architecture in Venice (IUAV).

His itinerant teaching work across Europe, the Americas, and beyond fuelled his constant and impactful passion for the formation of generations upon generations of students, who subsequently became expert professionals in multiple fields and who today are scattered all over the world (Chiapponi 2018).

3. The role of HfG in generating a new design culture

The Hochschule für Gestaltung in Ulm was founded to be an international experimental centre dedicated to theory, research, and development in the domain of industrial design (https://roericht.net/hfg-synopse/aufbau). Lindinger wrote in the catalogue of the *Ulm School* exhibition that the ideas that sprang up there were "a message destined to the whole world". A more than reasonable statement, given the international composition of the school's academic staff and its stated educational mission, that of teaching an innovative approach to design during the post-World War II reconstruction period (Lindinger 1988).

Although its existence was brief, the HfG in Ulm is still today viewed as one of the leading design schools of the twentieth century: it was founded in 1953 and closed down in 1968. Beginning in 1954, Tomás Maldonado

contributed to defining the school's curriculum and subsequently also to devising a new and robust method of training designers. Kenneth Frampton stated in an interview that: "HfG was undoubtedly the most important school of design founded after the Second World War, not because of what it accomplished in terms of actual production nor because of the large number of designers who actually qualified there, but ultimately on account of the extraordinary level of critical awareness that it managed to sustain in its everyday work [...]" (Frampton 1974; Lindinger 1988).

The curriculum was initially divided into four streams: product design, visual communication, construction, information, with the addition, at a later stage, of film. It offered a four-year course of studies, at the end of which students were awarded a diploma. The course was structured as follows: in the first year, all students were required to take the Foundation Course, before going on to specialize in one of the areas just listed for the remaining three years.

The HfG was officially inaugurated on 02 October 1955.

Max Bill was rector initially, from 1955 to 1956, while six months later, in March 1956, a council of rectors was set up to run the school, a group that initially comprised the following members of the academic staff: Otl Aicher, Max Bill, Gugelot, Tomás Maldonado, and Vordemberge-Gildewart (Escot 2002).

The HfG, like the Bauhaus, offered a preparatory year known as the Foundation Course (Grundlehre), designed by Max Bill, to introduce the students to the various career paths within design. Part of the first-year curriculum was devoted to the fundamental principles of design or *Basic Design*, a term coined by Josef Albers, based on the course that he had delivered at the Bauhaus, at Black Mountain College in Asheville in 1933, and finally at Yale University (Huff 2009).

In 2002, Günter Hörmann and Martin Krampen came to Milano, and interviewed Tomás Maldonado about his experience at Ulm. On that occasion, he spoke about the challenging historical period and the difficult decisions to be made when he first came to teach at the HfG, especially in relation to teaching methods, given the school's goal of developing an innovative didactic approach: "[…] the issue was whether to continue the tradition of the Bauhaus or to distance ourselves from it. We chose to distance ourselves from the Bauhaus. That meant that we wanted to revisit traditional Bauhaus themes in light of the newly emerging circumstances of that given historical period, it was the post-WWII era in a Germany in need of reconstruction". Maldonado laid particular emphasis on the HfG's revisiting of certain

Bauhaus themes in the context of its Foundation Course. To cite his own words during the interview: "[…] The idea was to change approach, or rather, to identify a different approach, trying to permeate it with, to make it sensitive, receptive to scientific developments, and to mathematical and methodological studies with a bearing on what was actually needed to engage in design. So, it was a question of inheriting the ideas of the formal [Bauhaus] methodology, but adopting a highly mathematicized approach that was beginning to come to the fore at that time in the domains of problem solving and decision making - these were techniques that could be immediately applied to the field of design […]" (Hörmann and Krampen 2002).

Some years after this interview, in 2009 to be exact, Tomás Maldonado spoke, during a talk delivered in Weimar at the Festakt zum 90. Gründungsjubiläum des Bauhauses, about his "[…] lively exchange of letters with Walter Gropius […]" on some of his [Maldonado's] theories concerning "[…] the need to take on board the elements of continuity and discontinuity in the Ulm project with respect to the Bauhaus project […]". In this regard, he stated that: "I am personally more and more convinced that it is time to recognize without nostalgia, without any pretence of regret, that the Bauhaus, as an institutional model, has ceased to be relevant, for the simple reason that it is no longer equipped to provide appropriate responses to the pressing needs of our time […]" (Maldonado 2009).

On the other hand, in relation to how the legacy of the Bauhaus contributed to the Ulm school's approach to teaching design, we should note another memorable statement of Maldonado's concerning the merits of the Bauhaus school: "[…] The reason that I remain deeply attached to the Bauhaus, still today, is not the thousand small and big achievements that are usually attributed to it, but rather the great lesson that the leaders of the Bauhaus – the 'Bauhäusler' – passed on to us as their legacy. That is to say, the fundamental desire to seek out and to provide, by every possible means, socially and culturally innovative responses to the needs of the historical phase we have been destined to live in" (Maldonado 1963; 2009).

4. A new teaching methodology

Thus, Tomás Maldonado's keen interest in the field of education emerged at the time that the HfG was being founded in Ulm. He particularly focused his thinking on devising an innovate educational approach based on "cooperation among disciplines". A teaching method developed for the students at Ulm, the future designers of

the third industrial revolution, and for all those still keenly interested in revisiting aspects of the Bauhaus approach to teaching design, on which Max Bill had originally based the HfG's courses. In Maldonado's view, such aspects of the Bauhaus approach were no longer suited to the needs of the HfG in Ulm.

The first-year Foundation Course at the HfG had four stated objectives: "1. It introduced students to the activities of the different streams of the curriclum, and especially the methods in which these activities were grounded; 2. It familiarized the students with key issues in [contemporary] technological culture, thus informing them about the broader context framing specific design tasks; 3. It trained students in collaboration with other disciplines, thus preparing them to work on teams, or groups of specialists, in which it was crucial for each individual to understand the issues and perspectives of the other members; 4. It set out to rebalance differences in prior knowledge among students who not only had previously pursued different academic specializations but also came from different countries with different education systems." (Lindinger 1988, p. 45).

In 1955, when Maldonado took over responsibility for the Foundation Course at the HfG, he attempted to modify the didactic approach of the previous year, that of the Foundation Course directed by Max Bill which was in keeping with the Vorkurs developed by Albers at the Bauhaus.

Maldonado was a great admirer of Josef Albers, and especially of one part of his course. He wrote that Albers had taken on a very difficult challenge in devising the Bauhaus approach to teaching design and that he had risen brilliantly to meet this challenge by transforming a set of diverse, and partially conflicting, compoments - such as pedagogical activism, mystical expressionism, and an exasperated version of constructivism - into a functional and coherent teaching model (Maldonado 1963, p. 12).

Hence Maldonado took the latest didactic approach developed by Albers for the Vorkurs into account when formulating the HfG Foundation Course, but only maintained selected themes, namely those relating to the theories of Gestalt psychology, with a view to providing in-depth background to his exercises in visual perception (Huff 2009, p. 107). He set out to adapt the other themes to meet the new requirements for training students in design, with the goal of formulating a teaching approach that would be more consistent and in keeping with "technocratic-positivist ideology (the mathematization of the design process, and the shift towards "operational research" models"). Thus, Maldonado embarked on a structural and concepual reform of the Bauhaus didactic

model which he essentially saw as obsolete (Wick 1993, p. 285-286).

His ultimate aim was to rethink the profile of the industrial designer in the post-war era and above all to design an educational trajectory for designers that would be more in line with the changes then underway in the industrial and production sectors. He believed that this could be achieved by improving the didactic approach and contents of courses for designers, chiefly by adopting a method that was scientific, exploited the benefits of technology, and was interdisciplinary.

His educational strategy was focused on progressively enhancing learning based on "cooperation among disciplines", a guiding principle that was to inform his entire academic career as a teacher and researcher in the field of education (Maldonado 1963, p. 12; Neves and Rocha, 2013).

In one of his last books, he stated that: "[…] Interdisciplinarity and transdiciplinarity not only respond to an increasingly urgent need for cooperation among disciplines, but are also (and always have been) the expression of an inescapable universal vocation to knowledge. […]" (Maldonado 2010, p. 11).
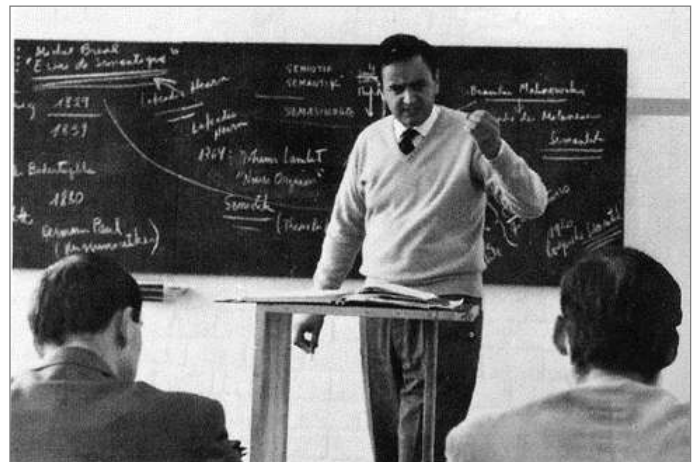
Fig. 1. – Tomás Maldonado, teaching at the HfG Ulm, 1958, source: photograph by Wolfgang Siol, © HfG-Archiv/Museum Ulm.

Tomás Maldonado was almost obsessively preoccupied by the desire to actively contribute to a total vision of culture, which he had counted among his intellectual goals since he was a young artist helping to found the Concrete Art movement in Argentina.

This was a project that towards the end of his life he characterized as "over-ambitious", but which was already present when he was a young artist, forshadowing his later keen interest in crossdisciplinarity - or, as he himself preferred to call it, the "third culture", which he

understood as an attempt to overcome the dichotomy between "hard" and "soft" sciences (Maldonado 2010, p. 9).

Therefore, coming back to the teaching of design in Ulm, from 1954/55 onwards, a new groundbreaking approach began to take shape, thanks to the crucial contributions of Tomás Maldonado and other lecturers invited to teach at the HfG. The change prompted by this novel approach, as mentioned earlier, not only impacted on schools of design and applied art around the world, but also on art academies, universities, and even other educational and training settings and institutions. The Ulm model, defined as a new approach to teaching design that combined formal, theoretical, and practical instruction with working for industrial partners on so-called 'development teams' directed by members of the HfG academic staff, would be introduced in various other schools around the world in the years spanning 1960 and 1962 (Lindinger 1988). In relation to the international spread of the HfG approach, Kenneth Frampton recounted in a 1974 interview that: "The questions that the Hoschschule für Gestaltung was asking itself ten years ago, are now consciously or unconsciously being posed by all schools of design and architecture, and the Hochschule's crisis of identity has become a universal malaise" (Frampton 1974; Lindinger 1988).

In light of these developments and due to some disagreements with Max Bill, Tomás Maldonado, viewed as the theoretician behind the HfG's founding principles, left the school and Germany in June 1967, heading initially for Princeton in the United States before moving to Italy in the 1970s.

When Maldonado began teaching in Italian universites, first at the DAMS in Bologna and later at Milano Politecnico, he was immediately popular with students. His extraordinary capacity for study and his deep and lively intellect both contributed to his charismatic style of communication in the classroom. He was also a talented storyteller. A particularly exceptional aspect of his teaching was how effectively he was able to convey his knowledge to his classes of students.

His intellectual generosity was amazing, and he was skilled at offering countless perspectives on any given topic. It came naturally to his listeners to allow themselves to be guided through a process of active cooperation and reciprocal exchange among the many disciplines that only Maldonado was able to draw together so masterfully. The outcome was generally a hugh enrichment and broadening of his students' collective knowledge base, along with a continuous flow of intellectual stimuli that inevitably gave rise to a pleasant, creative, and fertile "contamination" of the thinking of each individual student. His teaching was encyclopaedic in nature, and his method was based on active learning strategies informed by constructivist theories, which entailed the cooperative co-construction of knowledge with his students, whom he would invite to give seminars in the classroom. In sum, his method was new, stimulating, important, and revolutionary in its time. It was Italy's good fortune that he came here and formed many generations of students in this country also.

5. Tomás Maldonado's influence on the teaching of design

Maldonado's artistic experience as a student at the Escuela de Bellas Artes Manuel Belgrano in Buenos Aires up to 1941 and his involvement in the Concrete Art movement that he helped to found, shaped his artistic journey, which underwent a number of key changes. His classical figurative art training was reflected in his earliest paintings, which were dark and monotonous in character. Almost concurrently with this brief initial phase he began experimenting with abstract art. This shift is documented by works published inside and on the front cover of the first and only edition of the magazine "Arturo", which Maldonado produced in 1944 with his first wife Lidy Prati and a group of other artists from the Argentinian concrete art milieu. After this, Maldonado entered a full-blown experimental phase as an exponent of concretism (Escot, 2007). In embracing this new dimension of art, he was influenced on the one hand by constructivism and the avant-garde and on the other by his encounter in 1948 with European members of the concrete art movement: Georges Vantongerloo in Paris and Max Bill in Zurich. His trip to Europe and these contacts helped him to reinforce and consolidate his thinking about the role of theoretical assumptions in Concrete Art. The themes he explored in depth at this time included the objectives of the process of generating a work of art, the deployment of techical and operational strategies, and the consumption of the final work of art (García 2010, pp. 105-109).

When he returned to Buenos Aires, his art began to display a different compositional syntax: within the space of his paintings, he now used "more delicate" lines and geometric patterns with "weighted" chromatic interactions, yielding sophisticated compositions underpinned by unconventional visual-perceptual equilibriums and novel aesthetic relationships. Beginning in the early 1950s, Maldonado's art – and his underlying approach to the creative process and to constructing his compositions – began to display the sign of further change: some of his works were now clearly based on the application of scientific methods and mathematical calculations, the basic principles of concrete art.

Maldonado's keen interest in applying scientific theory and mathematical rigour to his art soon became his key focus.

This focus also played a key part in his subsequent choices: the contents he taught at Ulm were partly informed by new studies in the scientific domain which he systematically encountered in the course of his inquiry, as was his ongoing interest in concrete art (Neves and Rocha, 2013). In fact, as Willam Huff recounted in an essay for the catalogue of an exhibition on Tomás Maldonado, when he was put in charge of the Foundation Course in 1955/56, he introduced a strong "dose of Concrete Art" into the curriculum, which included two topics from the field of geometry: the theory of symmetry and the visual topology (Huff 2009, p. 108). An in-depth account of this intermingling of concrete art and the contents of basic exercises in design was provided by Marcel Herbst, who clarified that while some works by Concrete Art artists were not intended to follow rules, many others were based on rules, especially those of Richard Paul Lohse and Max Bill, because they were based on problems to be solved and mathematical calculations and could therefore easily be used as exercises in the context of a Basic Design course (Herbst 2017).

In 1988, to mark an exhibition on the HfG in Ulm that was held in the city of Genoa, Tomás Maldonado wrote:

"[...] it is not true that the Ulm school's theoretical framework was exclusively the outcome of our internal debate about the Bauhaus. What is more: I am convinced that outside of that debate there were disciplines and currents of thought that exerted an influence that was decisive in some regards for our understanding of design and how to teach it. It must be remembered that our curiosity was boundless, in those years, towards all that was new or seemed to be new. A feverish, greedy curiosity that was particularly attracted by certain disciplines that were just beginning to emerge at that time: cybernetics, information theory, systems theory, semiotics, ergonomics. But also, and in no lesser proportion, by other more consolidated disciplines such as the philosophy of science and mathematical logic. The impetus for our curiosity, studies, and theoretical struggles came from our desire to provide a solid methodological basis for design work (Lindinger 1988).

Hence the Foundation Course headed by Maldonado underwent key changes that entailed the introduction of interdisciplinary theories, systematic analyses, and practical experience, thereby contributing to shaping the HfG's offering to students of the new design. This development went hand in hand with a restructured curriculum, whose composition over the four-year duration of the course, as shown in Fig. 2, gradually progressed from mainly basic training in non-applied design in the first year to mainly applied design subjects in the fourth (Campos, Roldán, Sánchez Moya 2015).

The innovative didactic approach that Maldonado brought to Ulm did not just concern the new disciplines introduced into the Foundation Course or the contents of his own Visual Methods module (introduction to visual education), but subsequently also the introduction of other disciplines as part of new courses that were to further modify the HfG curriculum. Furthermore in 1958, Maldonado also proposed publishing a school journal, the HfG Journal Ulm, as a vehicle for presenting and disseminating the ideas developed at the HfG and the students' work to a community of designers, academics, and other professionals around the world.
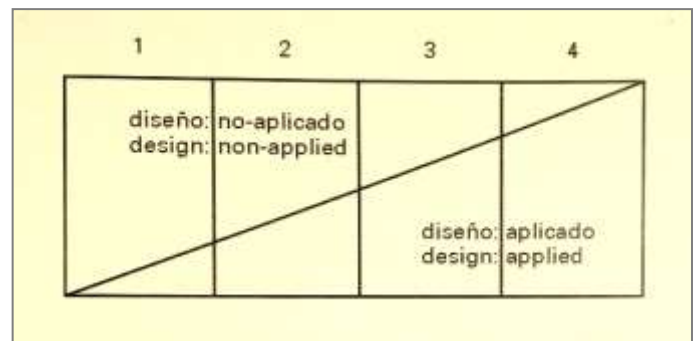
Fig. 2. – The curricular model developed by Tomás Maldonado for the HfG at Ulm (Lindinger 1988).

6. Tomás Maldonado: courses and teaching methods

Hence, from the early years of the HfG, Tomás Maldonado was actively involved in teaching courses there: in 1954, he was an assistant lecturer on the Foundation Course (Grundlehre) headed by Max Bill, while in autumn 1955 - and up until 1967 - he became a full lecturer.

The academic programs from those years document that in 1955, Tomás Maldonado taught visual methods to the first-year students taking the Foundation Course (Grundlehre). Beginning in 1958, he also taught a course in semiotics to the second and third year students in the visual communication and information streams, while in 1966/67 he taught theory of design to second year students of product design (Lindinger 1988, pp. 280-282).

Hence, Maldonado's interest and disciplined enthusiasm in those years were channelled into meeting the need for innovation in the teaching of design. But what constituted an innovative approach to teaching design in that era?

Maldonado believed that learning could be strengthened by leveraging knowledge from different disciplinary fields via interdisciplinary and transdisciplinary work. His own innovative teaching was informed by scientific research and the analysis of statistical data (Leopold 2013).

Giovanni Anceschi, one of Maldonado's students at the HfG, wrote in an article about the foundational nature of Basic Design: "[…] which means claiming that the act of giving shape must be tackled using logical-conceptual and scientific instruments, and also means bringing design inside, and up the level of, the 'connective tissue' of the sciences […]" (Anceschi 1983, p. 21).

Hence, Maldonado's focus as a teacher was on defining an experimental teaching model for the foundation course in design, which was to include some of the themes covered in Josef Albers' Basic Design course, but would also be based on Maldonado's own intense quest to incorporate the scientific method, with the utimate aim of teaching design in such a way as to lay the ground for students to learn different modes and techniques of representation. He also introduced systems thinking, which he applied to many of the topics that he taught at the HfG, and which enabled him to devise extremely impactful learning experiments (Aydemir 2018).

Indeed, in relation to his approach to teaching depiction/representation at the HfG, Maldonado emphasized in his interview with Hörmann and Krampen that "[…] depicting has nothing to do with representation and so it was important to teach, those who needed to learn representation, a different way of going about it […]" (Hörmann and Krampen 2002).

He would begin his classes by providing a theoretical introduction, followed by analytical exercises: bidimensional and tridimensional exercises and studies for applied design, to be conducted using visual representation tools and techniques.

In his book *Reale e virtuale*, published in 1992, Maldonado wrote, in relation to the auxiliary resources used in design (models, exercises, graphs, etc.), that:

"[…] You do not design or communicate with elaborate three-dimensional representations only, but also with two-dimensional ones that are produced spontaneously, which are intuitive in relation to a problem needing to be solved [...]. But drawing, especially *drawing to design* is a type of modeling that, as we are taught by contemporary cognitivist psychology, raises a series of issues that are far from trivial. Because drawing to accomplish design simultaneously takes the form of drawing while designing and designing while drawing. And this interactive co-existence between the means (drawing) and the end

(designing) enables progress towards or outright identification of the desired solution." (Maldonado 1992, p. 102). Maldonado's visual methods classes were based on active learning techniques, serving to prepare students for subsequent visual training that would be interdisciplinary and crossdisciplinary, drawing on constructivist and connectionist theories among others.

The practical bidimensional and tridimensional exercises were carried out using traditional visual representation tools and techniques. Drawings were produced manually, in order to stimulate the brain hand-eye coordination with an extraordinary care and precision demanded.

The point of the exercises was to guide the students, in a way that was supportive but rigorously non-directive, towards solving scientifically formulated problems in a systematic and self-directed manner.

In a study on learning from educational experiments, Ayse Zeynep Aydemir at the MEF University di Istanbul, defined the experimental educational activitiy conducted at the HfG and specifically Tomás Maldonado's systems-thinking approach as based on a technique known as "scalelessness". This term describes a work method whereby details and concepts are first presented on a small scale and subsequently translated into a design process, but also revisited to make changes. The timeline in Fig. 3 illustrates the deployment of the five categories of educational experiment defined by Aydemir in design schools across the world. These categories are participation, systematicity, complexity, linearity, and simultaneity. Among them, it is interesting to note that experiments based on systematicity first appeared in the early 1950s, which is precisely when the HfG was founded in Ulm.

Tomás Maldonado's classes in visual methods required his students to engage in sophisticated exercises in design. From the outset, he himself devised and set these exercises, with a view to guiding the students towards meaningful, reflexive, and mindful learning outcomes.

All possible resources, including instruments, materials and techniques, were made available to the students, who were assigned the task of solving problems using geometric formulas or mathematical calculations. These practical exercises were systematically supplemented by moments of collective and individual reflection, as well as by discussion of the strategies that individual students had deployed to define their personal solutions.

The approach just outlined is confirmed by the written testimonies of William Huff and Gui Bonsiepe, both of whom took Maldonado's foundation course as students.
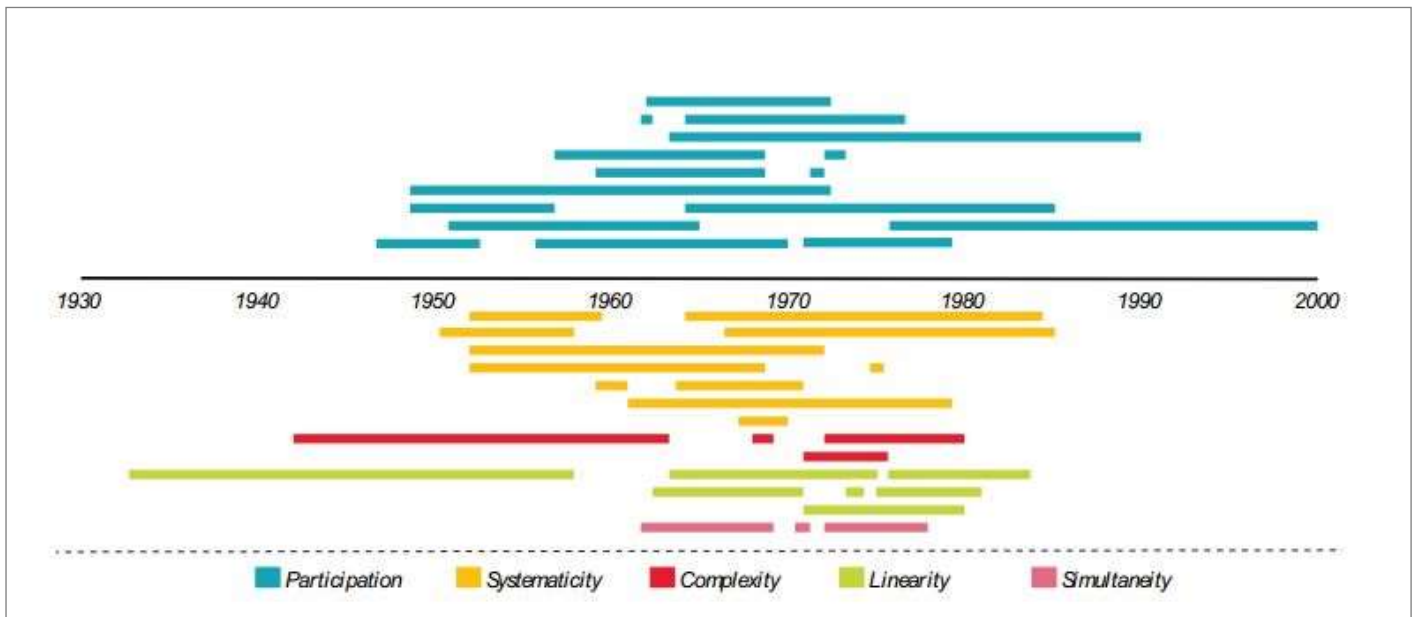
*Fig. 3. – The graph shows the majority of educational experiments conducted in design schools, divided into five categories and arranged along a timeline from 1933 to 1990 (*Aydemir 2018).

Gui Bonsiepe, who went from being a student to teacher, first at the Department of Product Design and after at Visual Communication from 1961 to 1968. He recounted that Maldonado, who had taken over responsibility for the first year of the HfG course in 1955, would began his course with the in-depth analysis of a set of exercises, also incorporating the required mathematical background and Gestalt psychology into these classes. Bonsiepe also stated that: "The foundation course exercises were also designed to develop the students' aesthetic abilities and were described as non-applied exercises in design, to distinguish them from the applied exercises in solving practical problems to which the subsequent years of the course were devoted" (Bonsiepe 2019, p. 126).

The summary table in Fig. 4 below is a key educational and historically valuable document that is held in the HfG-Archiv/Museum Ulm. It sums up the themes and a set of exercises that Maldonado devised for the first-year foundation course students taking his visual methods module.

William Huff, also a student of Maldonado's and later himself a teacher on the foundation course at the HfG in 1963 and 1965-1968, wrote that Tomás Maldonado's foundation course included ten practical exercises, whose original German titles invented by Maldonado are reported in brackets: 1. Sierpinski's surface (Sierpinskifläche); 2. Peano's surface (Peanofläche); 3. Weierstrass curve (Weierstrasskurve); 4. black as a colour (Schwarz als Farbe); 5. symmetries (Symmetrien); 6. exact - non-exact (Genau-Ungenau);

7. non-exact - exact (Ungenau-Genau); 8. perception of space (Räumliche Wirkung); 9. equilibrium of three surfaces (Gleichgewicht dreier Flächen); 10. interferences (Störung). He further added that "For the three-dimensional exercises, it was necessary to also take classes in finite mathematics, the theory of symmetry, groups theory, and visual topology" (Huff 2009, p. 111; Bonsiepe 2019, pp. 141-142).

In addition to these first ten exercises, Maldonado devised others for the students of Visual Methods in 1956-57 and over the following years (Huff 2009, pp. 111-112; Neves and Rocha 2013).

Most of these exercises included the use of colour in the form of a single hue or gradient, depending on the solutions that were sought/found in fulfilment of the task set by Maldonado. This meant, as earlier mentioned, that the students were required to complete the exercises manually with traditional drawing equipment because computer technology was not yet available to them. Nevertheless, Maldonado was already speaking to the students about cybernetics (founded by Norbert Winner in 1947), complex systems theory, computational calculus, information theory, and the theory of signs.

The first exercises that required the use of colour by applying the laws of geometry and mathematical calculation included the Peano/Hilbert curve and Sierspinki surface, both key elements in the development of fractal objects as studied by Benoït Mandelbrot (Lindinger 1988, p. 47).
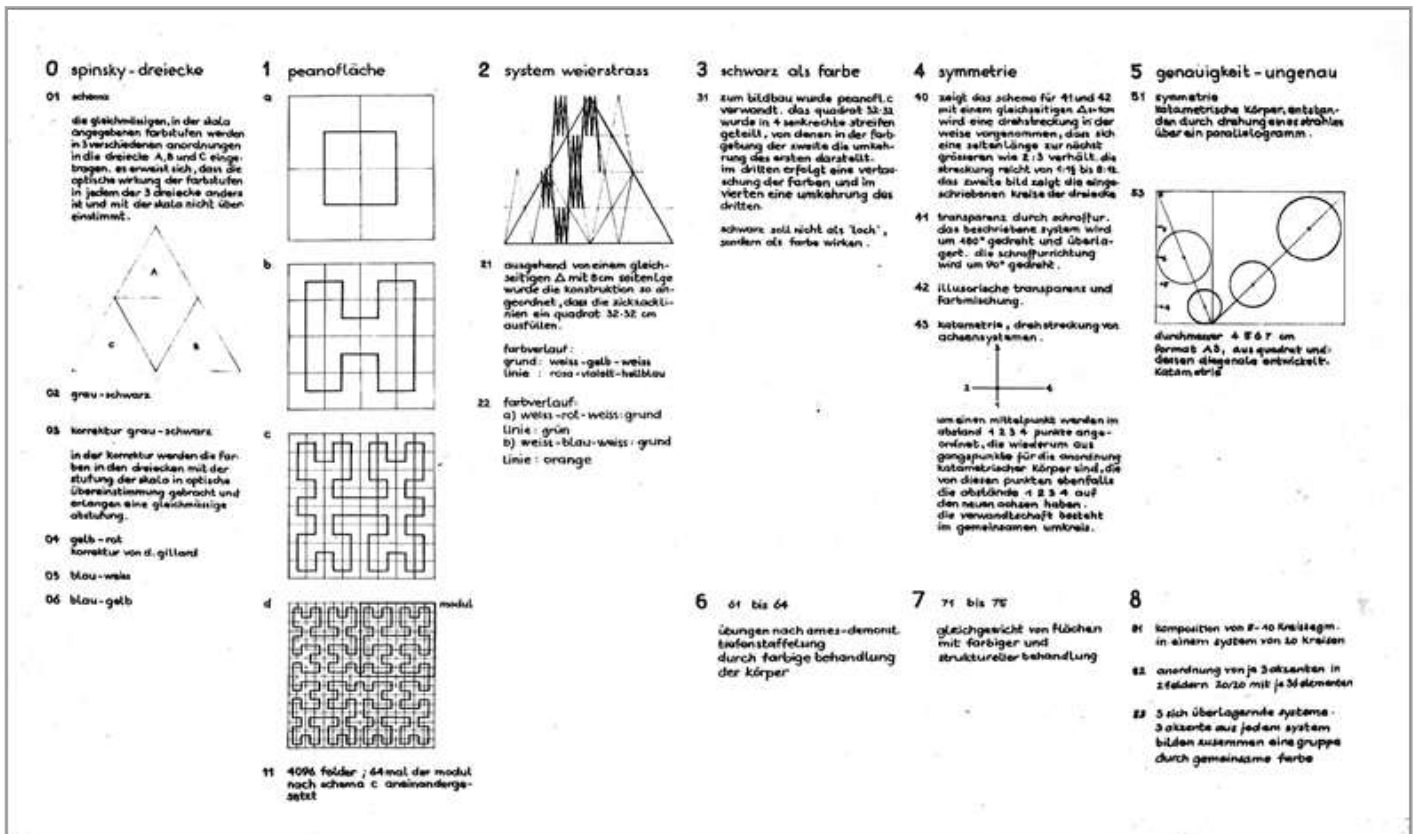
Fig. 4. – Chart showing the themes of the exercises assigned to the students attending Tomás Maldonado's Visual Methods course in 1955/56, source: HfG-Archiv/Museum Ulm. The following are the English translations of the titles of six of these exercises (numbered from 0 to 5): 0. Sierpinski's surface (spinsky dreiecke or Sierpinskifläche); 1. Peano's surface (Peanofläche); 2. Weierstrass curve (system weierstrass or weierstrasskurve); 3. black as a colour (schwarz als farbe); 4. symmetries (symmetrien); 5. exact - non-exact (genauigkeit - ungenau).

If we now go about analyzing these exercises, which were part of the foundation course common to all four design curricula offered by the HfG, we can clearly identify the interdisciplinary and crossdisciplinary approach that Maldonado worked so hard to achieve.

The even more interesting aspect of these exercises is the mathematical-scientific component leveraged by Maldonado to initiate the students into learning about the use of colour and the value of colour visual perception with and without colour.

In stressing the importance of knowing how to use geometry, while observing that not all designers are equally competent in this regard, William Huff described how Maldonado used to introduce his tutorials: "[…] Tomás Maldonado applied the formula of semiologist Charles Morris to his explanations of design, likening design, or at least applied design, to language. Indeed, both possess the same three basic components: the syntactic component, the semantic component, and the pragmatic component: that is to say, structure, meaning, and function. Differently to applied design, which is essentially linked to architecture, graphic design, and industrial design, *basic design* is purely concerned with the syntactic component or 'structure'. Now, 'structure' may be defined as the 'organization of different parts'. Two terms, therefore: 'parts' (or 'elements') and 'organization' (or 'relationship'). System and structure are interchangeable in practice, albeit that the former evokes a notion of dynamism and the latter a notion of staticity. In mathematical language, which constitutes a special way of describing structures, we use the terms 'members' and 'operations' [Huff 1984, pp. 36-37). Hence, some of the exercises that Maldonado assigned to his students displayed a key characteristic which consisted in the fact that the repeated component, once defined, would generate a particular kind of image (Neves and Rocha 2013).

In this way, Maldonado taught his students how to explore the relationships among, and organization of, the components of a structure (the overall image, the whole) and how to explore a structure composed of individual elements.

In his exercises, he used colour to identify any of the three compoments of the language of design listed above by William Huff. Depending on the exercise assigned, colour could be used as a syntactic component, that is, as an element communicating the structure of a figure/image. Or colour might be used to highlight the element making up a structure (form). Or, finally, as a component that was pragmatic and functional to the message that was to be conveyed (function). Colour was thus understood to be a variable within the system of signs or signals with which information may be communicated and visually encoded.

To better exemplify how these exercises were executed in practice, the next figures display the products of four actual practical assignments carried out by three of Maldonado's students (Fig. 5 - 6 - 7 and 8): Dominique Gillard and William Huff in 1955-56 and Urs Beautler in 1956-57.

The images in Fig. 5 reproduce an execution by the student Dominique Gillard, of Exercise No. 1, entitled "Sierpinski's surface" (Sierpinskifläche). Maldonado used this exercise to introduce students to the theme of the relationship between full spaces and empty spaces; and to how these spaces are visually perceived and understood by the observer when four shades of the same chromatic hue are used to make explicit the functions of full versus empty space. Thus, in the example shown, each set of same-sized triangles was assigned one of the four shades of blue (from the smallest to the biggest and vice versa). The different patterns thus created provide the observer with a perception of the different triangles as empty spaces or full spaces, depending on how the shades of colour were arranged.

The task assigned to the students was to construct a geometrically derived surface by applying the mathematical formula for Sierpinki's triangle, invented - as its name suggests - by Waclaw Sierpinki in 1915. Construction of this figure begins with an equilateral triangle, whose internal space is divided into four equal parts so as to generate four smaller equilateral triangles. This operation can be iterated recursively such that each new triangle can generate four more and so on.

The choice of Sierpinki's triangle for this exercise is intended to pave the way for interdisciplinary teaching/learning: it is a fractal geometric form derived from the application of a mathematical formula; its replication gives rise to a surface; the addition of chromatic colour schemes can produce different visual perceptions of this surface, thus enabling the communication of alternative messages.
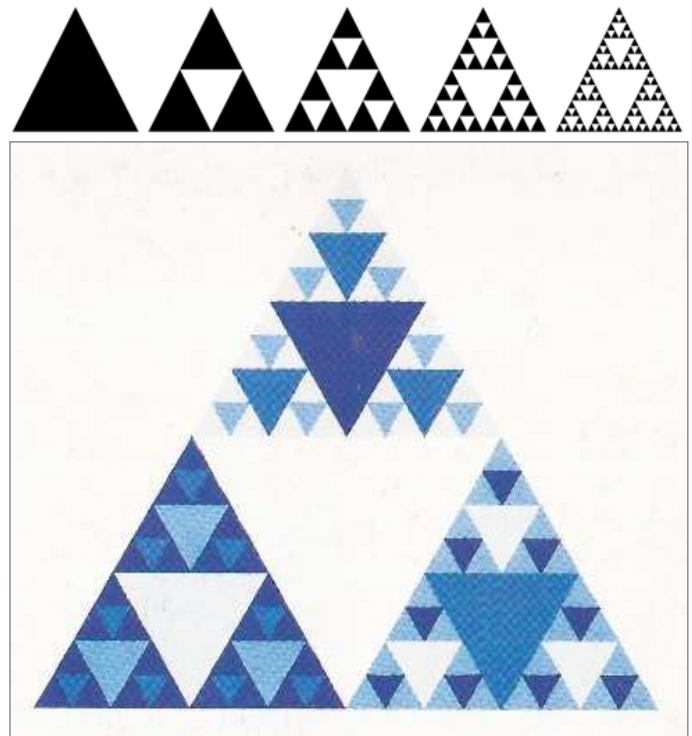
Fig. 5. – Practical exercises with "Sierpinski's surface" (Sierpinskifläche)*, a.a. 1955-1956, lecturer: Tomás Maldonado, student: Dominique Gillard,*
source: HfG-Archiv/Museum Ulm.

Fig. 6 offers a worked example of Exercise No. 2, again executed by Dominique Gillard, and entitled "Peano's surface" (*Peanofläche*): These images were created by applying the curve theorized by the Italian mathematician, logician, and applied linguist, Giuseppe Peano, in 1890. A Peano curve is defined as a continuous line that is generated by joining all the points on an orthogonal grid situated on a given plane. Again, this exercise was based on multiple iterations of the basic Peano curve sequence. The first image in Fig. 6 is a line drawing of a surface defined by a structure. This structure, as stated, was generated by recursively repeating the primary Peano curve sequence, in order to trace a continuous line with only one start point and one end point, as an expression of the tension between the finite and the infinite.

In this drawing, the dark/light contrast was then used to highlight the basic sequence, then used to create the structure in the second image. The latter was coloured and defined using graduated shades of two chromatic colours: blue and red. The use of the orthogonal grid in both images was of crucial assistance to the student in planning how to lay out and vary the basic sequence across the plane. The differential shading of the two colours produced two geometric figures. The student's primary focus was on attempting to make these two figures equivalent, such that neither could be defined as the main figure and neither as the background figure.
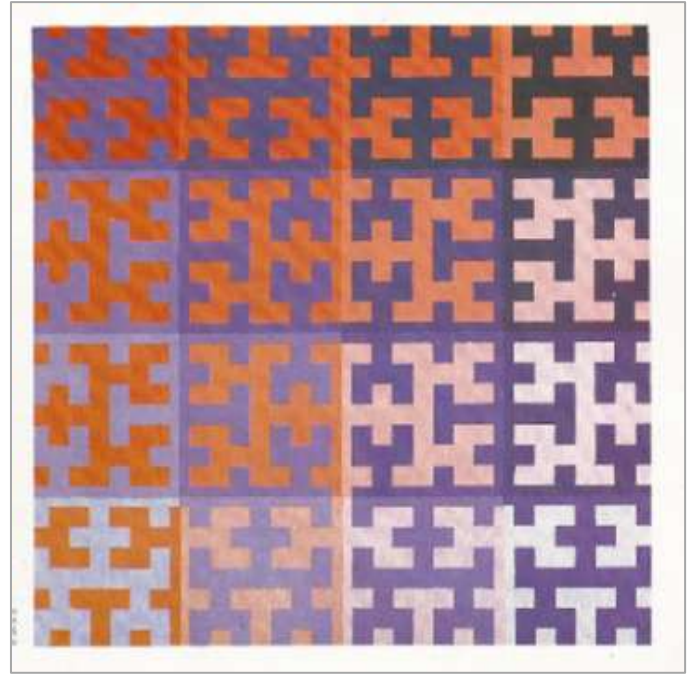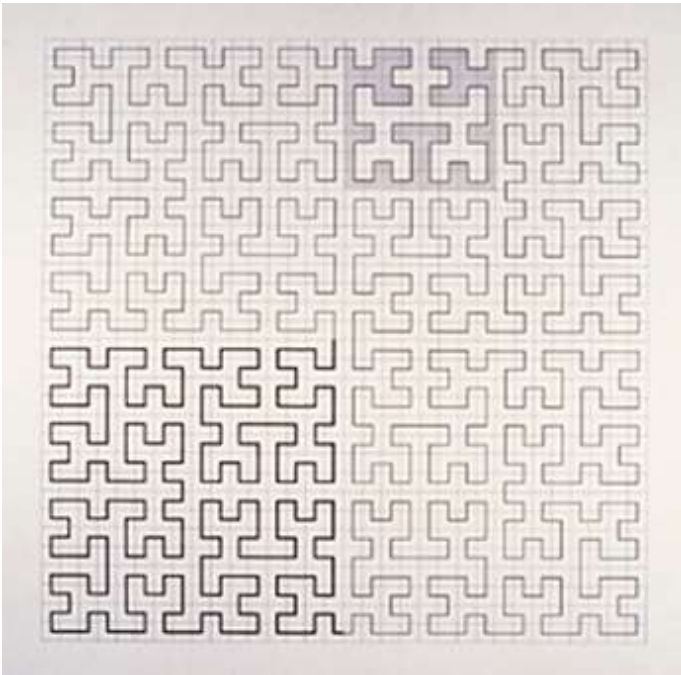
Fig. 6. – Exercises performed using "Peano's surface" (Peanofläche), academic year 1955-1956, lecturer: Tomás Maldonado, student: Dominique Gillard, source: HfG-Archiv/Museum Ulm.

It has been shown that ambiguity is best achieved by using colour values with the same intensity of light and luminosity value, or complementary colours with the same degree of luminosity. In this exercise, the Peano curve was used with a specific teaching purpose in mind: Maldonado chose this curve as a basic figure to work on with a view to fostering rational creativity. Creativity, in that this form was already a recognized artistic phenomenon; and rational because the use of the orthogonal grid was an effective means of encouraging a rigorous approach to the design and execution of the exercise.

With regard to Exercise No. 3, entitled "Weierstrass curve" (system weierstrass o weierstrasskurve), for which no worked examples could be sourced, this too involved using a linear geometric construction, namely a Weierstrass curve, to create a figure out of empty space. The educational purpose of this exercise was to address the visual perceptual problem of the relationship between foreground and background figures, a theme that was very important to Maldonado.
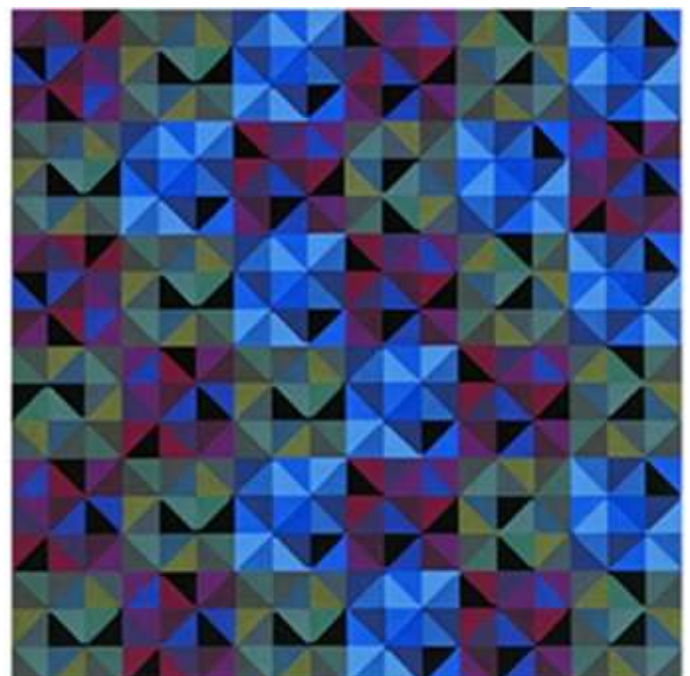
The image in Fig. 7 exemplifies Exercise No. 4. entitled "black as a colour" (Schwarz als farbe) and was executed by Urs Beautler. This practical focused on the use of black in the context of chromatic colours.

Here, Maldonado's teaching aims were to "train" the students' visual perception, refining their ability to visually discriminate between colours and to pick out certain tonal values from a set of chromatic interactions. The exercise on black as a colour was based on a combination of contrasting levels of brightness, such that black is not perceived as generating a "hole" effect but functions as a colour. Correct solutions showed that black, when featuring among set of solid colours, could be perceived as "brightened" and as a colour in its own right.

Fig. 7. – Exercise in "Black as a colour" (Schwarz als Farbe)*, academic year 1956-1957, lecturer: Tomás Maldonado, student: Urs Beautler,*
source: HfG-Archiv/Museum Ulm.

Again, this representation was produced via a recursive pattern of geometric shapes on a square base: starting

from an orthogonal grid formed by minimun sixteen squares, each square was divided in half diagonally. The underlying grid allowed the students to rationally plan out the horizontal, vertical, or rotational patterns they wished to create, by applying the laws of symmetry.
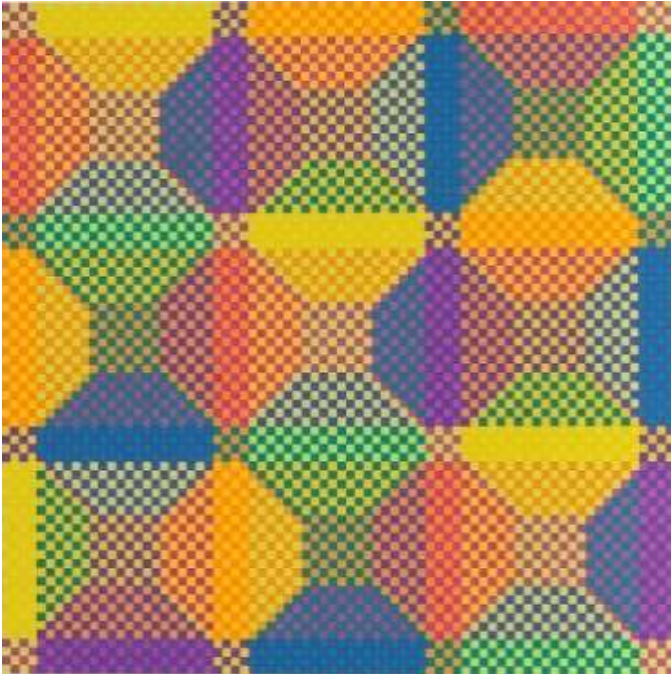

Fig. 8. – Exercise No. 7 "Non-exact - exact" (Ungenau-Genau), *academic year 1955-1956, lecturer: Tomás Maldonado, student: William Huff, source: HfG-Archiv/Museum Ulm.*

Fig. 9. – Tomás Maldonado, teaching at the HfG Ulm, 1954, with Hans G. Conrad, Almir Mavignier, Martin Krampen and one more student, source: Photograph by Sigrid von Schweinitz Maldonado, © HfG-Archiv/Museum Ulm.

The image in Fig. 8 shows a worked example of Exercise No. 7, executed by William Huff. Entitled "non-exact - exact" (Ungenau-Genau) by Maldonado, in this practical, the students were invited to create an image by innovatively applying the technical means at their disposal to work with conventionally accepted formal elements of colour, texture and consistency.

With regard to the program of HfG courses in Theory of Colour specifically, the names of some of the non-permanent lecturing staff who taught on this module were listed by Herbert Lindinger in a piece written for the *La scuola di Ulm* exhibition catalogue. Hence, we find Aemilius Muller as lecturer in "Theory of Colour" between 1954 and 1955; Mervyn W. Perrine as lecturer in "Theory of Perception" from 1958 to 1961; and Fritz Seitz as lecturer in "Theory of Colour" between 1967 and 1968 (Lindinger 1988, p. 40 and pp. 280-282).
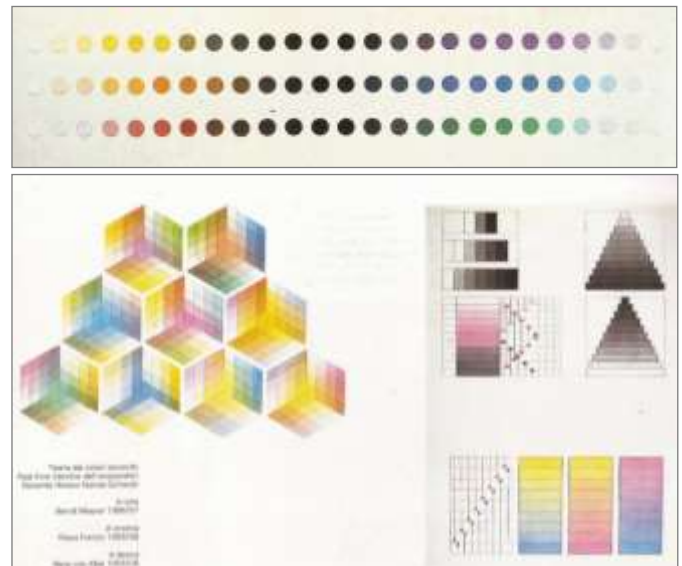

Fig. 10. – These watercolour drawings represent Paul Klee's theory of colours as interpreted by three students at the HfG: top: Bernd Meurer 1956/1957, left: Hans von Klier 1955/56 and right: Klaus Franck 1955/56, lecturer: Helene Nonné-Schmid, source: HfG-Archiv/Museum Ulm.

The Figure 10 documents three practical exercises in colour carried out by HfG students: Top: Bernd Meurer (1956/57), left: Hans von Klier (1955/56) and right: Klaus Franck (1955/56). These watercolour drawings were executed as part of the course in colour theory taught by Helene Nonné-Schmidt, an ex-Bauhaus student who had taught colour alongside Josef Albers, albeit with different educational objectives. The task assigned to students was to interpret Paul Klee's theory of colours. These three drawings are highly representative of the methodological approach adopted by Helene Nonné-Schmidt during the courses she taught at the HfG from 1953 to 1958. This approach reflected her Bauhaus

training, and stands in contrast with the innovative scientific approach adopted by Tomás Maldonado to initiate his students into the culture and theory of colour.

7. Conclusions

This article documents the brilliant educational work of Tomás Maldonado while a teacher at the famous HfG in Ulm. The key pedagogical challenge that he pursued was to develop an innovate method of teaching design that was informed by the scientific method and an interdisciplinary and transdisciplinary approach.

We have drawn here on the abundance of material held in the HfG Ulm archives (*HfG-Archiv/Museum Ulm)*, together with Maldonado's former students' written accounts of the teaching contents and methods that characterized his courses at the HfG, to present his perspective on teaching design and at the same time to note the pioneering nature of his ideas. With the aim of fostering the teaching and learning of new design competences, he developed a novel educational method that influenced how design was taught in a number of different countries around the world.

Among the subjects that he taught at the HfG, we have focused on the Visual Methods module that he delivered as part of the first-year Foundation Course. Even more specifically, we have homed in on the theme of educating to colour as a strategic cultural aspect of designing visual communications and other design products.

The practical work produced by the students who attended Maldonado's classes in Visual Methods offer unique and extraordinary examples of the innovative nature of his teaching experiments with respect to other contemporary approaches. The new principles that he formulated and introduced at the HfG, beginning in 1955, combined scientific method with mathematical calculations and emerging new discipines such as ergonomics, visual communications, signs theory and information theory.

In relation to his teaching of colour more specifically, we have observed that it was aligned with his overall educational approach, with a similar emphasis on scientific method, interdisciplinary and transdisciplinary input, and new Gestalt studies on visual perception. His theoretical classes on colour drew on analytical studies and applications of logic, as well as constantly appealing to geometry, discrete mathematics, and set theory.

Among the practical activities described here, some are extraordinary examples of complex aesthetic-formal exercises based on mathematical formulas, the theory of symmetry, early cybernetics concepts, and early versions of fractals such as the Sierpinski triangle and the Peano/Hilbert curve.

In sum, thanks to the contribution of Tomás Maldonado, the Ulm school in the 1950s saw the emergence of a new pioneering perspective on design and the role of the designer as well as on how the process of designing and producing products was likely to be in the future. In those years, there was still no mention of environmental sustainability, but Maldonado's approach laid the theoretical ground for the introduction of environmental design by virtue of his principle of "cooperation among disciplines".

8. Acknowledgments

9. Statement on conflict of interest

The author declares that no conflict of interest, real or potential, including financial or personal links with other persons or organizations, up to and including the three-year period following the presentation of this work, that could inappropriately influence the reported research outcomes.

10. Statement on sources of funding

11. Short author biography

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Color and materials in design didactics. Design of a playroom and relaxation area for children – case study

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ABSTRACT

This project was focused on providing design students with practical knowledge regarding the use of colors and CMF (color, material, finish) implementation in public space, interior, and product design. In cooperation with a textile company, they designed a space at the day care center where children and teenagers were able to relax and participate in therapeutic meetings and conversations. During project, students became familiar with the ways of defining colors and their symbolism (moodboards, graphs, semantics), CMF design, influence and use of taints in interiors (simulation of perception in different light conditions, Panton Viewing Booth Light Box), parametrization of coloring (NCS, Pantone, RAL, CMYK). The color scheme was elaborated in the process of consultations with experts and psychologists and executed with the participation of users of the facility. The idea also involved introducing young people to interesting places in Silesia. This purpose was served by the wall map of the region and original seats, which featured the landmarks marked on the map. The added value of this project was presenting students with the opportunity to work with an actual business (textile producer). This involved learning about the technological background, organizing dedicated workshops and consults with experts, and the possibility of working with materials provided by the producer. The implemented project is an example of a model program of cooperation between representatives of higher education – Academy of Fine Arts and Design in Katowice and a public utility institution – Community Day Care Center at the Gniazdo Foundation.

1. Introduction

This article presents the findings of an educational project concerning colors design and CMF (color, material, finish) implementation in public space, interiors, and product.

The Academy of Fine Arts in Katowice conducts research and didactic program regarding color design. During lectures, case studies and practical assignments, students acquire basic knowledge and skills at parametrization and design of color.

Fig. 1. Didactic program at AFA Katowice (color design).

2. Project

Within the design and didactic activity, a pair of students executed a project of an unusual playroom and relaxation area for children and teenagers of the Katowice Community Day Care Center at the Gniazdo Foundation (Fundacja Gniazdo, 2021). The project was carried out in collaboration with a textile producer, Lech Fabrics Company (Multimedia, 2021). In accordance with the notion of corporate social responsibility (IDEO, 2015, 29), it assumed a purposeful participation of the company in young designers' education as well as improving a fraction of the world for a group of local children in the Silesia region.

2.1. *The premise of cooperation*

The headquarters of Lech Fabrics Company, the leading importer and producer of fabrics, is in Kostrzyn, Wielkopolskie Voivodship, Poland. There, one can see their modern offices, a showroom presenting their upholstered furniture and a warehouse of 14 thousand square meters. Lech Fabrics was chosen as a didactic partner of the Academy of Fine Arts and Design due to its 40 years' experience and technical potential as well as its values. It is a family business, oriented towards social activity, sharing knowledge and experience with young designers.

The cooperation between the Academy and this business partner involved a series of trainings and presentations of possible fabrics application as well as cooperation in terms of production and implementation of the designed product.

The company granted students' access to technological facilities, organized dedicated workshops and expert consultations of fabric designers regarding the selection of colors for the interior. The producer made its fabrics available to students as well. Their knowledge about color sampling and designing color tendencies was expanded by the product range offered by the brand.

Students found the entire process especially motivating due to the fact that their efforts were purposeful, oriented towards the result in the form of guaranteed application, rather than abstract student practice. Beside the possibility of their design being implemented, recognized and rightfully rewarded, both designers and producers were encouraged by the social aspect of their work – helping children and teenagers from the Community Day Care Center at the Gniazdo Foundation.

The designed interior provided these young people with a good space to read books, study, relax, conduct therapeutic meetings and meaningful conversations in small groups.

Stages of the design process resembled those of classical service design (Brown, 2009, 45–63) in permanent contact with the future users and the support of experts (representatives of the interior design industry).

One could distinguish:

- Building of the team and mutual inspiration:
  - Creating the team consisting of students, Academy teachers, employees and pupils of the Gniazdo Foundation, employees and experts of Lech Fabrics;
  - Defining areas of cooperation and users' needs during workshops;
  - Didactic workshops for Academy students led by Lech Company;
  - Workshops with the users (listening and forming the hierarchy of needs, drafting mood boards of ideal space, presentation of possibilities, arrangement of space, inspiration);
  - Interviews with Foundation employees and psychologists providing for designing in compliance with the users' needs.
- Generating ideas and prototyping regarding the service and the project:
  - Creating space mock-ups, color and fabric models;
  - Building usage processes;
  - Building and research of functional areas of the selected space;

- Colors research (perception of colors on fabric and the walls in changing light conditions);
- Studio visits in the manufacture and Poznań Fairs.
- Verification of the project:
- Contest method of displaying designed solutions;
- Modeling and prototyping;
- Technological consultations with the producer (implementation);
- Common application of the project in space (implementation involved pupils, employees, students) building community and shared responsibility for the project.

2.2. *Methodology*

In the process of students' projects development, where the conducted analysis translates onto the project concepts, a triple diamond methodology is often used (Design Methods Step 1: Discover, 2021). Developed by Design Council, it consists of 4 stages: discover (analyses, documentation, interviews), define (organizing information, building the brief), develop (design development, prototyping and testing) and deliver (implementation). This allows to organize the design process following the sequence: possibly the widest scope of analysis – drawing and formulating conclusions – return to unrestricted prototyping and building precise design concept.

The working group, consisting of the author and students conducting the experiments, used the following design methods:

a. defining the symbolism and taint (moodboards, graphs, semantics);
b. choice of color, materials and finish (CMF);
c. testing the effect and use of particular taints in interiors (simulation of perception of taint and fabrics in different light conditions by means of Panton Viewing Booth Light Box);
d. parametrization of coloring (NCS, Pantone, RAL, CMYK).

2.2.1. *Defining the symbolism and taint (moodboards, graphs, semantics)*

A group of students, assisted by a technologist of Lech Fabrics, created color moodboards that constituted the base for further project. A moodboard is a design method and creative tool which allows to define the character of project by visualizing its general concept (Stramer, 2007, 29). They also worked with a semantic differential, which is a type of rating scale designed to measure the connotative meaning of objects and concepts. On its opposite axes, a spectrum of contrary features is located, e.g., traditional – modern, everyday – festive, glossy – mat, chromatic – achromatic.

Students situated their project objectives in a chosen area of the spectrum built on these features. To define the features for the spectrum and the context of the project, they created a mind map – a diagram used to visually organize information. Emphasizing the semantic aspect of design makes one aware of the effect that its basic properties (shape, material, texture, color, size) have on the users' psychophysical and physical response. In the design process, these properties serve as variables and determine the form of design.

Fig. 2. Using a moodboard for defining the design color scheme.

2.2.2. *Choice of color, materials, and finish (CMF)*

The accurate selection of color, materials and their finish greatly influence the functional aspects of a designed product and its final appearance. All the properties are interdependent, and their configuration affects the entire design.

Color perception results from many factors classified by The Optical Society (OSA) as early as 1943 (Zausznica, 1959, 357–360). They are known as attributes (properties) of color perception and include i.e. brightness, tone, and saturation, but also: size, shape, location, fibrillation, scintillation, transparency, luster, glow. This classification was the first attempt to expand the three basic parameters by additional factors – the basis of the current CMF design. It must be noted that none of these aspects should be considered separately from the others. Considered all together, they allow to accurately define the character of a given color.

In the project, matching the coloring and materials to the users' needs followed from consultations and was conducted with the support of Lech Fabrics experts. They

assisted students in solving design problems by applying appropriate materials and technologies.

Enabled by the possibility of using a wide palette of fabrics made available by the producer, students could analyze every CMF aspect and become aware of their effect on the project.

The method of evaluation of individual factors (color, material, finish) and their influence on the recipient was visualized by means of the C/M/F indicator (Becerra, 2016, 49) which allows to understand the significance of each element in the following aspects: functional / emotional attributes, quantitative facts, performance / aesthetic requirements, characteristic keywords.

2.2.3. Influence and use of taint in interiors (simulation of perception of taint and materials in different light conditions by means of Panton Viewing Booth Light Box)

The choice of colors was elaborated in the process of consultations with experts and psychologists and carried out in the participation process with users of the day care center. The process included taking pictures of specific color combinations in the context of particular spaces, choice of materials and temperature of light, and accounted for the color preferences indicated by the users.

Students made coloring samples and used them for several simple experiments to observe the correlation of change of lighting and color impression depending on the type of object (flat / three-dimensional), kind of pigment (print, acrylic paints) and the substrate (paper, textiles).

The first analysis concerned observing the chosen color on a simple three-dimensional object (cube). It was intended to make the young designers aware of the difference in appearance of the tested taint when used on the 3D rather than flat surface. The next experiment regarded the selected set of wall acrylic paints. The observation of how natural light influences color perception in the interior was expanded by testing the color samples in the Panton Viewing Booth Light Box. Another analysis, carried out in the same conditions, used the selected fabric samples from the palette of materials provided by the producer. Due to different types of light in the interior (natural daylight, artificial light: neutral and warm), students were able to observe the phenomenon of metamerism on all tested surfaces, textures, and color variants. This experiment helped them understand the design issue of appropriate lighting of color on textiles and acrylic paints. The described analysis was intended as observation and visual experience of the changes without taking measurements or cataloguing the results. Such an approach allowed the young designers to learn how to correlate and evaluate
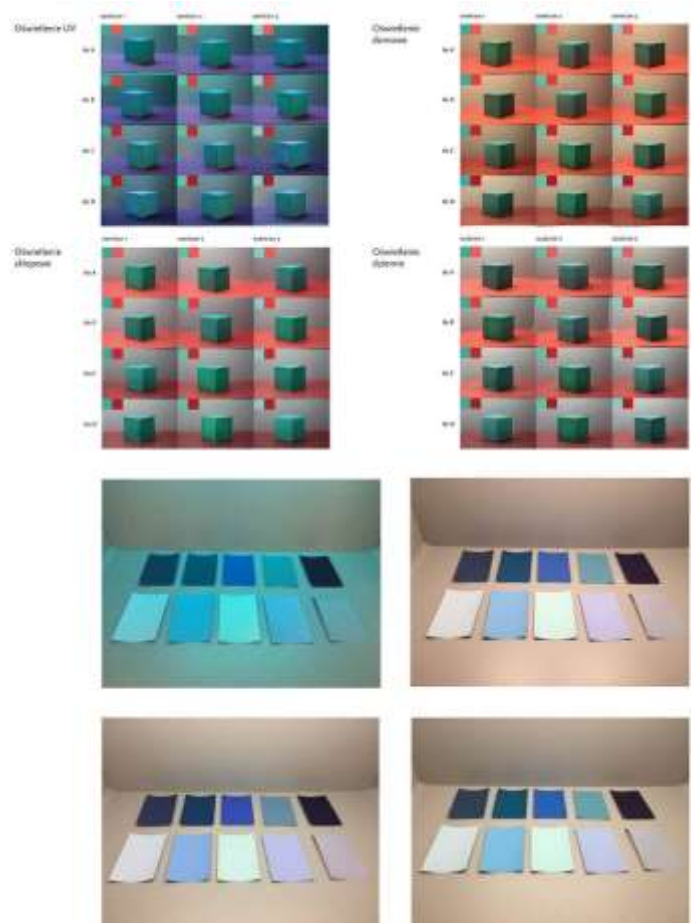

Fig. 3. Simulation of specific light conditions for selected color samples.
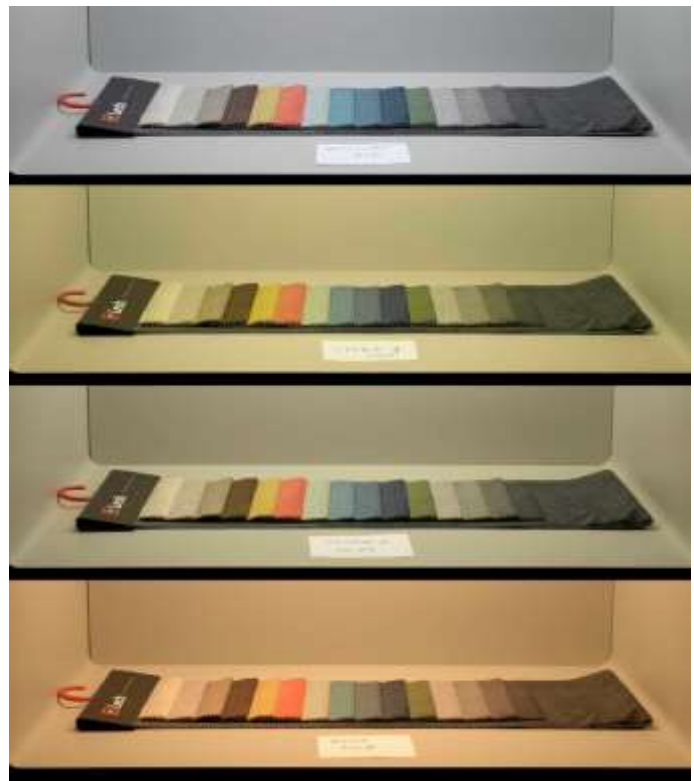

Fig. 4. Simulation of specific light conditions for selected fabric samples.

selected components of the future design and provided them with tools to verify or validate their intuitive ideas and individual preferences.

General description of research conditions: selected components of the future design and provided them with tools to verify or validate their intuitive ideas and individual preferences.

Photographs of samples were taken with a digital camera equipped with the full frame matrix type CMOS, without low-pass filter, factory-calibrated. There were fixed settings of exposure in every photograph, 100 ISO, f/14, ¼ sec. The balance of white in the camera was 5000K (daylight, D50). Pictures were taken in a darkened room, samples were lit only with Panton Viewing Booth Light Box, using the following light sources:

1) Daylight (D50) color temperature 4990K, fluorescent lamp with light intensity 2120lx.
2) Store 1 (CWF) color temperature 3806K, fluorescent lamp with light intensity 1625lx.
3) Store 2 (TL84) color temperature 3980K, fluorescent lamp with light intensity 1921lx.
4) Home (Inc A) color temperature 2847K, fluorescent lamp with light intensity 1299lx.

Measurements of color temperature and intensity for light source installed in the device (Panton Viewing Booth Light Box), were provided by the producer.

Adobe RGB was chosen as the color space of saved files; neither postproduction nor digital editing were conducted.

The above conditions of experiment record allowed students to observe the color temperature of the selected light source in comparison with natural daylight (D50) and its influence on perception of the color of materials used in the study, as well as the difference of light intensity between particular light sources. The device parameters, which determined the type of lighting, were selected for the most precise imitation of the actual changes of light color in the designed interior (daylight, and warm/neutral artificial light).

Experiments conducted by students focused on cognitive aspects and were their first experience of changes in color depending on the lighting parameters. This research, therefore, carried a good didactic value for the young designers.

2.2.4. *Parametrization of coloring (NCS, Pantone, RAL, CMYK)*

The project of an unusual playroom and relaxation area for children and teenagers of the Katowice Community Day Care Center at the Gniazdo Foundation required from students the parametrization of selected elements (furniture, walls, fabrics, finish) according to the nomenclature of numerous color standards.

Color mapping applies various theoretical models and color charts. Developed individually, they currently co-function on the market of interior, product and visual communication design. The previously assigned areas, typical of each individual chart, are becoming increasingly composite. For instance, charts typically used in polygraphy, now have their variations dedicated to textiles; those characteristics of the paint industry, have expanded their use and are now applied in parametrization of the coloring for plastics and advertising materials etc.

Therefore, regardless of the substantive content of the project, every designer should master the use of any type of color chart and be able to correctly transpose the selected color values as accurately as possible. A real challenge of the project documentation can be indicating a particular, uncharacteristic color, which could be closely defined by means of all the above-mentioned notation standards.

In the case of this project, the students team had to define the color scheme for the color sets of wall paints, wood varnishes, plastic elements, textiles. They applied the systems of NCS (NCS Colour – Universal Language for Colour Commmuication, 2021), Pantone (Pantone Colour, Chips & Colour Guides | Colour Inspiration | Pantone UK, 2021) and RAL (erleben and Farben, 2021). Among those three, only NCS could be considered as a color model organized and described in a manner characteristic of such compilations (Munsell color system, Ostwald model etc.). Pantone and RAL are charts of ready color recipes used in design.

This experience provided students with a good and thorough training of color charts use and color translation between the charts.

Beside designing the color scheme of the room, the idea was to present interesting places in Silesia and thereby familiarize young people with history, build the identity and community of place, as well as spark their imagination. This purpose is served by the wall map and original seats, which present places marked on the map.

The resulting color layouts are composed of illustrations and characteristic typography, applied to natural fabrics and wood. Employing various variants of textiles (padded furniture, decorations, panel partitions, curtains etc.), the entire project responds to the functional needs of its users.

Fig. 5. Project of workplace. Matching materials and colors to the function of an interior.

Fig. 6. Project details. Textile elements, featuring original prints, dedicated to the relaxation area.

There were many aspects directly connected with the need for modification of the interior's function depending on the time of day, number of participants and the character of classes conducted in the room. The functional layer of the project assumed a selection of colors to allow the intensive use of the work area by several children (easily cleaned and durable materials, neutral color scheme) as well as effortless reorganization of the furniture and shelves (frequent touching).

Attention had to be paid also to the psychological aspect in reference to the relaxation area and therapy (using natural materials, pleasant to touch, calming color scheme).

The project allowed for personalization of the interior by children (textile boards with their drawings and modular poufs with interesting visual components). The interior design included original elements, such as seats combining the features of comfortable ottomans with didactic materials (each seat bears an original print and

information about an important monument of Silesia or an interesting place), and the wall covered in a textile map, on which children can mark the landmarks visited in the region. The final color scheme was developed in consultation with experts and psychologists and executed in participatory process with the users of the facility.

Children articulated the need for "their own" private space, which would resemble a well decorated house rather than specialist group therapy rooms. As a result, the team of young designers and experts had to face various challenges and meet diverse expectations.

3. Conclusion

The project aims to promote the creative and innovative solutions, using textiles in public spaces, in reference to interior color design. Its added value was presenting students with the opportunity to work with an actual business (textile producer). This involved becoming familiar with technological background, organizing dedicated workshops and consults with experts, and the possibility of working with materials provided by the producer. The knowledge regarding color charts and designing color tendencies was acquired in the practical context of the product range offered by a particular brand. The project was implemented by the end of 2019 and nominated for the Śląska Rzecz 2020 – Silesian Icon 2020 award (Gołębiowska. e., 2020, 86–87) in the Service category as an example of a model program of cooperation between representatives of higher education and public utility institution.

4. Conflict of interest declaration

5. Funding source declaration

6. Acknowledgment

7. Short biography of the author.

Anna Kmita Graduated from the Academy of Fine Arts in Katowice, majoring in design. Habilitation: "A set of three projects related to color design in visual communication". She leads research and design programs focused on heritage and restoring forgotten elements of design, history, culture, and identity of Silesia. The programs ended with publications and implementations of results in cooperation with the local businesses.

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Video documentation of the project:
https://www.facebook.com/391765764330507/videos/2649985155019664

Visual grouping: a study on preponderances of color or shape in Match-three games

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ABSTRACT

A category of entertainment that stands out for its popularity is the Match-three electronic games, in which the player needs to form groups of, at least, three similar objects to score points. Thus, the study of how players perceive visual groupings becomes an important tool for future developments. This research investigated color and shape relationships in Match-three games, looking for preponderances in the visual grouping of color or shape in the psycho and neurological response. For this, a bibliographic and an empirical research were carried out. A beta and a final version of two Match-three games, created for this research, were applied to a sample of 52 people. One of the games was black and white with different shapes, and the other, colored formed only with one shape. Results of the bibliographical research indicated that the perception of visual grouping of color and shape depend on the elements with which it is interacting in the visual field, and this determines if one type of grouping will be perceived with prominence. The empirical research showed that, for the category of games studied, visual groupings of color are perceived more quickly and more easily than visual groupings of form.

1. Introduction

A type of entertainment that grew with the spread of smartphones (Coutinho 2014) were digital mobile games (Gualà et al. 2014), and the popularization of the category of Match-three games still stands out in Brazil (Fig. 1).
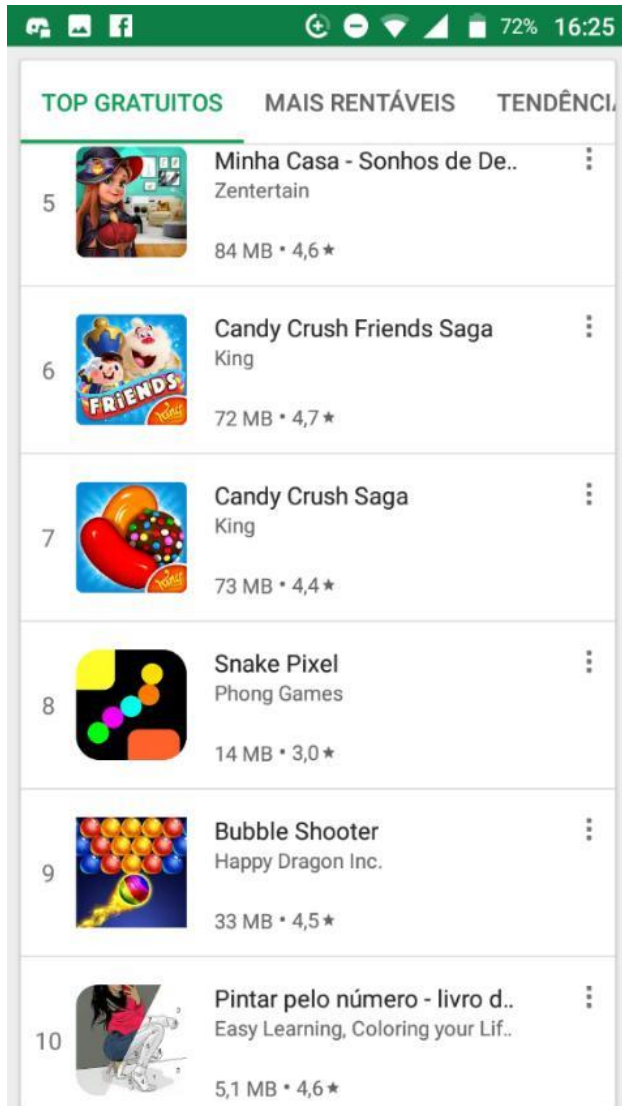

Fig. 1. Printscreen of ranking of most downloaded casual games in Brazil, from the 'Google Play' platform at 02 November 2018 [1].

For people with normal vision, the perception of visual groupings is the most important part to be observed in the mechanics of this type of game, as its dynamics is limited to making groupings of at least three similar icons by color or shape to score (Fig. 2) (Juul 2010).

This study aimed to understand the response in relation to visual groupings of color and shape and visual comfort in the scenario of digital games of this type.

Fig. 2. Printscreen of 'Candy Crush' game, an example of Match-three game [2].

1.1. *Visual grouping in psychology and visual language*

Visual perception is defined in modern psychology as an active combination of sensorially received stimuli and organic interpretation, which organizes and relates them to previous experiences (Dondis 2007).

Arnheim (2008) affirms that visual groupings can be perceived by similarity, proximity, clarity, configuration, direction, speed, consistency (regular, homogeneous) and contiguity (merged forms that are seen as unique).

The author indicates that color and shape belong to the same grouping perception, the similarity one. He highlights that depending on how the objects are related in the visual field, they will be seen more or less united: "A visual object is all the more unitary the more closely its elements are in factors such as color, clarity, speed and direction of movement." (Arnheim 2008, pp. 79)

Kepes (1944) determines that a visual grouping can be perceived through two factors: similarity due to the object's own quality or proximity. This author affirms that similarity groups appear to be perceived as more unified than groups formed by proximity. For Dondis (2007), in contrast, proximity is more important than similarity.

The three authors, Anheim (2008), Dondis (2007) and Kepes (1944) place color and shape as characteristics belonging to the same type of visual grouping, which is similarity.

1.2. *Visual grouping on neurologic studies*

For neuroscience, the difference in the perception of color and shape clusters directly depends on the way the brain perceives, processes and relates these two types of visual stimuli. Several studies debate whether color and shape are perceived in different regions of the brain or whether they are processed by the same group of neurons. This affects the understanding of speed and the way visual information is perceived (Aymoz and Viviani 2001).

In an experiment carried out by Moutoussis and Zeki (1997 apud Rentzeperis et al. 2014), the authors understand that different visual attributes presented at the same time may not be perceived simultaneously, which would indicate different ways of processing.

The Moutoussis and Zeki 'color and form experiment' consisted of presenting a screen to some participants, half of which was colored with a checkerboard pattern that alternated between red and green, and the other half with gray bars alternating the inclination from left to right.
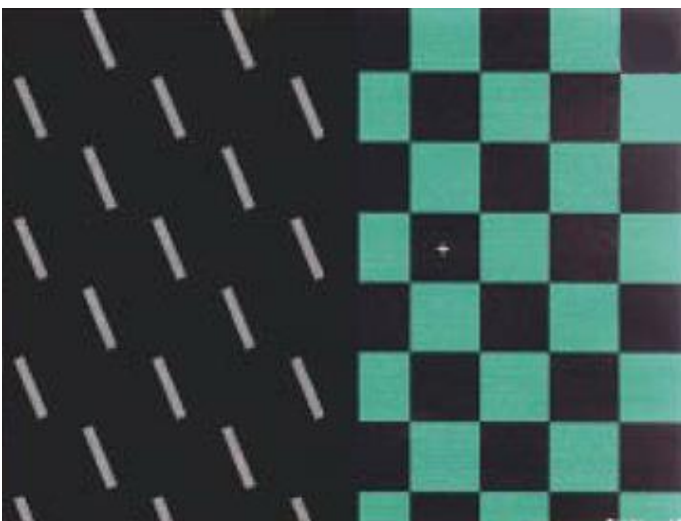

Fig. 3. The 'color and form experiment' of Moutoussis and Zeki from 'Functional segregation and temporal hierarchy of the visual perceptive systems (1997)'.

The participants had to combine the colors of the squares with the orientation of the bars that were presented simultaneously. The changes in color and orientation occurred in the same proportion, presented at various phase differences (0-360⁰, varied in steps of 10⁰, randomly). For some of these differences, the sensed color and form values were different from the real ones. The temporal disparity then indicated that colors were perceived approximately 63 milliseconds before form (Moutoussis and Zeki 1997).

In another experiment, Aymoz and Viviani (2001), tested 20 students at the University of Geneva with normal vision. Participants were located 50 cm from a computer monitor and had their responses to stimuli monitored by a standard graphics program.

The experiment investigated the processing of three visual attributes: color, shape and movement. There were three conditions, one for each possible pairing of these attributes. Stimuli were combinations of two values for each attribute (red / green, circle / square, fixed / mobile). In each condition, the stimuli changed twice quickly, each attribute changing asynchronously between the two possible values. The participant should inform which change he perceives first (Aymoz and Viviani 2001).
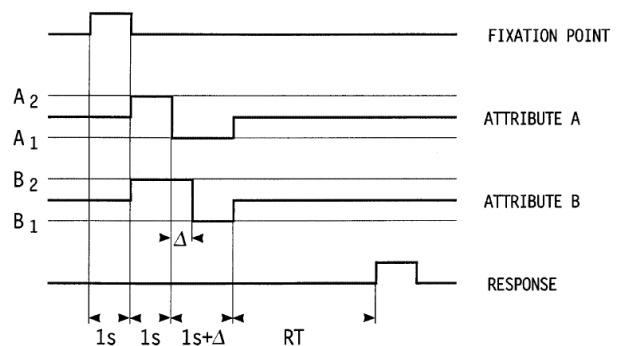

Fig. 4. Aymoz and Viviani experiments (2001). Timing of the events within trials. A1 and A2 (B1 and B2) are the two possible values of the stimulus attributes A and B. In this example, the initial stimulus (A2B2) lasts for 1 s, changes into the intermediate stimulus (A1B2) which lasts for Δ ms (SOA), and is finally transformed into the final stimulus (A1B1) which lasts 1 s.

With the experiment, they computed 13 values of asynchrony, and transformed them into estimates of perceived time. The results showed that color and shape are processed almost simultaneously, and the perception of movement is delayed by about 50 milliseconds (Aymoz and Viviani 2001).

Clifford et al. (2003 apud Rentzeperis et al. 2014) tested the perception of color and orientation using sinusoidal gratings oscillating in color and orientation at the same time frequency and for a series of phase differences. They discovered that, depending on the speed of presentation of the forms, the asynchrony of perception changed.
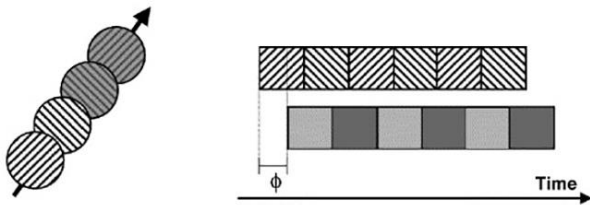

Fig. 5. Clifford et al. (2003) experiment at an oscillation period of 600 ms as a function of the relative phase of oscillation (ϕ).

It was found that for faster presentation rates, color and orientation were perceived at the same time, however, as the frequency of presentation decreased, the asynchrony between color and orientation increased. In the 1 Hz presentation, color perception preceded orientation in 50 milliseconds.

To explain the difference in perception in the two different contexts, Rosenholtz et al. (2012 apud Rentzeperis et al. 2014) propose a psychophysical model in which, depending on the target object of the vision, the vision system considers or disregards the rest of the visual plane, whether the eyes are looking for something in the scene or just following a target and disregarding the rest.

This disregard is closely linked to the locations in the brain where information will be processed. It can be processed together (color and shape), which would mean the same preponderance in the cognitive response, or processed separately, which would cause a difference in processing time.

Thus, studies move towards the understanding that, depending on the context and the relationships involved, neurons work in different ways (parallel or serial) and in different brain locations. Thus it is possible to state only that, depending on the interaction, different preponderances between color or shape will be noticed in the visual grouping.

2. Empirical Research

To understand the relationship of preponderance in visual groupings of color and shape in Match-three games, two games and a qualitative questionnaire were developed by the authors to test the speed with which players group similar sets.

One of the games applied was black and white, with well-defined shapes (square, circle, rhombus and triangle). The other was polychromatic (multiple hues), with only one shape (circles) of pure RGB hues (yellow, blue, red and green), with the same brightness and saturation.

The games and the questionnaire were applied to a sample of 52 people, between 18 and 30 years old, attending higher education at ESPM College in São Paulo, Brazil. Female and male individuals were tested, equally divided into 2 groups, with each group containing 26 people. The selected subjects claimed not to have color blindness or any other compromising chromatic pathology.

The tests had a determined order of application, half of the tested people started playing the first, the other half the second game, so that the learning of the mechanics did not influence the speed of resolution of the objectives.

Each group of 26 was divided into two new groups of 13 people, who alternated the game initially tested (13 started with game 1, the rest with game 2).

The average resolution speed of each game was compared in order to understand possible preponderances in the cognitive response of color and shape grouping.

Before the final tests, a beta test was carried out to detect aspects that could be improved. Regarding the application of the tests and methodology, the sample used was 12 people, 6 males and 6 females.

A qualitative questionnaire for data collection was carried out at the end of each test. It asked the name of the individual for further identification of the data, age, biological sex and the following questions:

- Which one of the two games, black and white or color, did you find easier to group? Why?
- Which of the two games did you find most pleasing to see? Why?
- Did you notice anything different in the way you perceived the groupings in the two games?
- Do you have any observations or suggestions? If so, which one?

3. Game development

The games were programmed on the game engine 'Unity 3D', with the aid of a basic free code for Match-three game from the blog Dimitris-Ilias Gkanatsios [3]. A

programmer (Mario Sérgio Affonso Junior) was hired to assist in the preparation of the two games. The visual part of the games was developed with the Adobe Illustrator vector image program.

Both games work the same way, having the same programming code, just changing the visual part, ensuring that the two tests had the same level of complexity.

At the end of each game, the game program automatically generates a report informing the number of groupings made, name and time in order to better organize the information collected. The groupings that are considered in the report are those of moves made manually, that is, formations that occur in a chain are not counted.

Both games have a black background and differ from other games in the Market that have complex and/or textured backgrounds. However, this form of presentation was chosen to isolate the object of this research, in this case, the color and shape groups, without distractions.

For the empirical test, the authors intended to create greater contrast between figure and background. According to Csillag (2015), light colors are perceived prominently in contrast to a black background. This way, it was decided to use figures with 100% brightness on a black background.

For the black and white game, four basic shapes were chosen: square, rhombus, circle and triangle. The square had reduced height in comparison to the other geometric shapes in order to appear the same amount of empty area around it, guaranteeing the perception of individuality when close to other squares. Thus, as previously explained, it is also possible to form visual groupings by proximity of items but the objective of our study is the grouping by similarity.

Both the colored and the black and white game have 100% brightness of their items and a black background (R = 0 G = 0 B = 0; # 000000), in order to obtain equivalent contrasts.

Both games have a home screen where information about the participants is given, such as name, biological gender and the option of the game being colored or monochrome.

After selecting one of the games to play (previously determined), a preparation screen will appear for the player, with the intention of allowing the player to decide when to start the game.

The two games have a 30-second timer on the upper portion of the screen (Fig. 4 and 5), indicating the time remaining to group the largest possible number of

similars. The stopwatch was implemented as the limiting mechanic of these games.
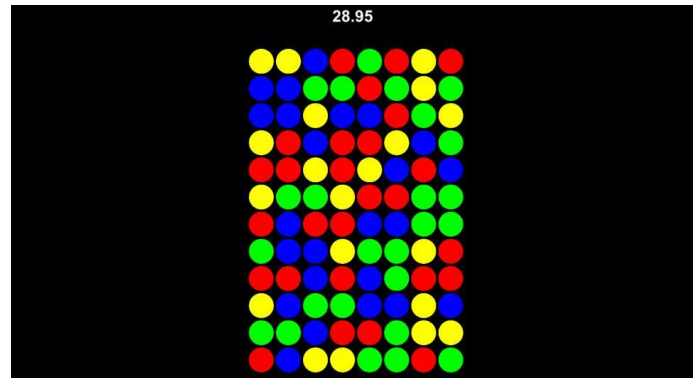

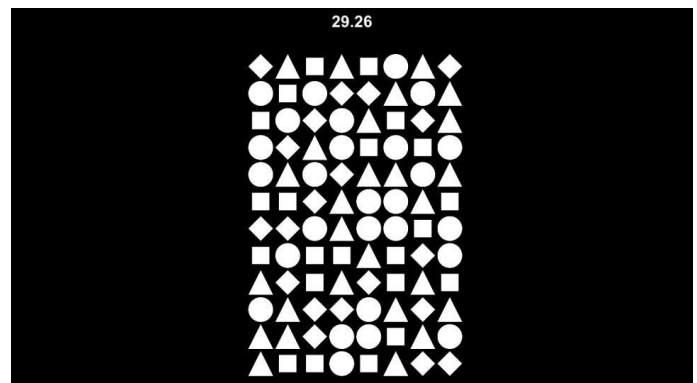*Fig. 6. Printscreen of the colorful game designed by the authors.*

Fig. 7. Printscreen of the black and white game designed by the authors.

After the 30 seconds of the stopwatch, a game over screen will appear indicating the end of time, with the possibility of returning to the home menu and starting the other game.

4. Beta test

A beta-test was carried out, before the final tests, in order to check if there was a need for adjustment in both games and in the questionnaire.

It was found that the visual groupings of color (125 combinations in total) were better perceived by users compared to those of shapes (91 combinations in total).

Nuisances with the saturation of the colored game have been described by the players, however the modification of this parameter was not perceived relevant, because despite the discomfort, the results indicated that the perception of visual groupings by color remained

prevalent. Instead of discomfort, other players described that the saturated color becomes important for a good differentiation of the hues.

The beta test revealed that the "game over" screen caused a negative feeling in the players, therefore, the red "game over" was replaced by "end of the test". With this change, this bad feeling, which could change the test results subsequent to the first game, was overcome.

5. Final tests

At the beginning of the test, respondents were asked if they had any type of pathology that compromised their visual understanding of color or shape. In addition, permission to collect data was requested by completing two copies of a consent form. After that, a brief explanation of how the tests worked and how to perform the combinations in the game was given.

At the end of the test with the games, the qualitative questionnaire was administered through Google Forms.

The final games found that visual color groups were perceived more quickly by players, as soon as the programs accounted for a total of 644 color grouping and 435 form grouping made by the participants.

These results were made up of 47 people (90%) who make more color groups than form, 3 females and 1 male (8%) who made more combinations by shape than by color, and 1 female (2%) who made equal combinations in games of color and shape.

A little difference was noted between the number of combinations made by male and female players in both games. In the color game the male respondents made 333 combinations, while the female respondents made 311. In the black and white game, the male respondents made 221 combinations and the female 214.

It may be concluded that, even though male participants had made more combinations, the preponderance in combinations of the colorful game is perceived, in both sexes.

The qualitative questionnaire based on the players perception also demonstrated greater facility and comfort to make colored groups.

For the question: "Which one of the two games, black and white or color, did you find it easier to group? Why?", 90% of respondents (47 people) replied that they preferred colored groups, 8% shaped ones (4 people) and 2% (1 person) presented an incongruous answer.

For people who responded that they had a preference for colored groupings, the following aspects were highlighted: greater visuality, more visible the groupings, ease of grouping, easy assimilation, more agile, more attractive, forms not sufficient to integrate the player and the game, and greater emphasis in perception.

For people who responded that they preferred shape groupings, the following aspects were highlighted: shapes are easier to differentiate, shapes help to group, more pleasant to play with less intensity than color and colors cause confusion.

For the question: "Which one of the two games did you find most pleasing to the eye? Why?", 79% of those surveyed (41 people) replied that they preferred the colored game, 21% the form game (11 people).

It was highlighted that for the color test: there is more familiarity in playing colorful games, it is easier to understand the possible combinations, you can better identify the colors, the homogeneous shapes and saturated colors help, it is better to see, livelier and happy, better mental organization, there is greater visibility, more homogeneous space between shapes, it is more intuitive, more attractive, more flashy and inviting, because it is colorful it is more beautiful, the shapes were not enough to cause 'integration' with the game, greater differentiation and visualization, the black and white game it is more confusing and difficult to concentrate, color highlights the vision more, 'it hurts' less the eyes, greater similarity in the grouping, less effort to group, in the form everything is mixed.

For the black and white test, the highlight was: the colored game confuses the vision, which is more pleasant, which caused relaxation and making the test less intense, personal preference for black and white, too saturated colors, more aesthetically pleasing, in the color game, the contrasts were unpleasant.

For the questions: 'Did you notice anything different in the way you perceived the groupings in the two games?' and 'Do you have any observations or suggestions? If so, which one?', not all participants had observations to make, the observations made stand out from the points already presented, as shown below.

In the black and white game: A 20 years old (20 y.) male (M) needed greater concentration to find the combinations. A 20 years old (20 y.) female (F) person noticed that she made combinations from the tips of the shapes and thinks that she did not make many combinations with the circles. A player (M, 19 y.) said that everything is perceived as a unique visual mass. Another player (F, 22 y.) 'fright' when the white shapes appear. Other one (F, 22 y.) took a long time to "understand" the shapes.

In the color game: a person (F, 18 y.) said finding the blue circle was easier. Other one (M, 21 y.) saw the feedback of groupings was more visible. A player (M, 18 y.) used the intensity of the colors to form combinations. Other one (F, 22 y.) felt easier to play with equal shapes. Another (M, 21 y.) thought that perceiving colors is more natural than thinking about which shapes are identical. A participant (M, 19 y.) said that he managed to form "color spots" that facilitated the game.

Overall: One player (F, 21 y.) found the tests very fast and other one (M, 19 y.) thought it would be beneficial for the game to combine colors with shapes.

6. Final Considerations

The previously cited visual language and psychologic studies of Arnheim (2008), Dondis (2007) and Kepes (1944), show that color and form belong to the similarity aspect of visual groupings, and the greater the resemblance, the greater the perception of grouping.

In addition, the previously cited neurologic studies of Aymoz and Viviani (2001), Clifford et al. (2003 apud Rentzeperis et al. 2014), Moutoussis, K. and Zeki, S. (1997) and Rosenholtz et al. (2012 apud Rentzeperis et al. 2014), show that sometimes color and form are perceived without prominence; sometimes color is perceived before, and for lower exibittion rates, color is perceived before form. It may be concluded that the visual grouping of color and shape are perceived in different ways depending on the context in which they are inserted.

With the results obtained from our empirical research, it may be concluded that the factor that facilitates the speed of visual grouping in a Match-three game is the use of different colors (hues) in the game icons.

This study demonstrates that for visual groupings of color and shape in Match-three games, color is predominantly seen as a factor of better and faster assimilation of groupings. Most respondents also report greater comfort when playing the color test.

Based on this, developers are recommended to use color and shape combinations in their projects when differentiation is necessary. This will help differentiate objects by different and highly contrasting hues, as the user's response is quicker and easier for color combinations. Such differentiation can benefit the experience and user interface (UX and UI), making the action or gameplay more comfortable and intuitive.

7. Conflict of interest declaration

8. Funding source declaration

9. Short biography of the author(s)

Joyce C. Cavallini – Graduated in Design at ESPM College.

Paula Csillag – Professor Doctor at ESPM College, since 1999, lecturing in the Design Department. Research interests are related to color communication, visual language, color perception and color trends.

Notes

[1] Printscreen taken at the ranking of most downloades casual games in Brazil at November 2018, Available at: https://play.google.com/store. (Acessed: 02 November 2018).

[2] Printscreen taken at a stage of Candy Crush Saga at November 2018, Available at: https://play.google.com/store/apps/details?id=com.king.candycrushsaga . (Acessed: 02 November 2018).

[3] Complete tutorial by GKANATSIOS, D. (2015) of how to building a match-3 game (like Candy Crush) in Unity. Available at: https://dgkanatsios.com/2015/02/25/building-a-match-3-game-in-unity-3/. (Acessed: 25 April 2018).

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Is white skin really pink? Flesh color as a pink color in Western art and culture

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ABSTRACT

In this article, I determine the shades associated with the idea of a unique flesh color, retrace its history and emphasize its inclusion in the field of pink. I carry out this analysis in a transhistorical and transmediatic way. I will go through medieval texts, literary works, artists' writing, pictorial and abstractive work, as weel as other cultural productions like fashion, comics or animation. Based on this overview, I question the hegemonic position which leads to the long lasting association of pink color with complexion. I will also question this pervasive link with the system of race, since the use of pink indicates only the skin of white people — even symbolically —, understood as the color of the skin *in general*.

1. Introduction

Usually used to designate the color of the skin, the term "flesh" is a synonym of "complexion", or "skin tone". Many links cross path between the flesh color and the nuance we now designate as "pink", from medieval painting manuals to contemporary arts and fashion trends. More specifically, pink is used as a "flesh color" when it comes to representations of Caucasian skin — seen as typical of the so-called "white skin" — in painting, but also in sculpture, cartoons and comics (think of the pink face of Disney's Cinderella). Contemporary fashion and cosmetics also designate by the word "flesh" a set of products whose colors are supposed to refer to the color of the (white) skin. Regarding the naming of make-up products, the word "flesh" has been replaced by the term "nude", which is supposed to refer to a certain idea of "natural", that is to say without artifice. In literature, authors use pink to describe white skin too. In the poem "À une robe rose" by Théophile Gautier, the pink fabric of a dress is associated with the "light pink" color of a woman's skin (Gautier, 1850). Likewise, from a lexicological point of view, the flesh color is also considered as a shade of pink, after the skin tone of white people (Mollard-Desfour, 2002; Kuriki *et al.*, 2017; Zimmermann *et al.*, 2015).

However, the color of white skin is really neither pink, nor the same from one individual to another (due to tan, age, health, etc.). This specific generalization and simplification of the complexion of a large social group is actually associated with the concept of race. Race is a system of categorization and hierarchization of individuals according to morphological and/or cultural criteria. Skin color is one of the main criteria for forming these categories and the category of white people, to which the color flesh pink refers, is then symbolically and socially opposed to a broader set of non-white people [1] (and thus not represented by flesh pink) (Blanchard, Boëtsch and Chevé, 2008).

Similarly, several contemporary artists used pink as the one color that symbolically refers to the bodily experience common to all human beings. In these cases, pink relates to the flesh understood as mucous or as what is subcutaneous. Pink can then signify the organicity of the body, the experience of human life in a philosophical sense, or even the emotions perceived through the skin, therefore providing a psychological dimension to the color.

The purpose of this article is to outline how pink became the generic color of the (white) skin, but also how this generic color has become capable of signifying the very concepts of flesh, life and humanity. Based on a transmedia and transhistorical study, I will study how pink has become, over the centuries, the color emblem of white skin in Western cultures, then symbol of human color taken as a whole. I will also show how this construction intersects with the concept of race, and therefore how pink participates in its own way in the symbolic superiority of white people over non-white people.

2. The Flesh Color in Western History of Painting

In painting, the term "flesh" is employed as an equivalent to the rendering of the skin. "Flesh" is understood as a color term which designates the skin of white people as a whole. It often remains the only dermatological type represented by Western artists and approached by treaties on the arts. Skin appearance is historically at the center of the concerns of European artists, especially painters. Indeed, the representation in painting of the appearance of the color of human skin is a complex and technical challenge, "an inaccessible chimera" (Pernac, 2008). Ever since the time of the Ancient Greeks and Romans, the complexion was not limited to selecting color, but was rather a question of arranging the shadows and lights in order to provide the illusion of volumes (Lichtenstein, 1999), and also to transmit "the expression of the flesh" in all its dimensions, including tactile (Diderot and Le Rond d'Alembert, 1766). The qualities of the flesh in paint are also described with the Italian term *morbidezza* which means "suppleness", "softness", "tenderness" and "blur", a range of words which refers to the texture of the flesh and not to its color.

It was not until the end of the Middle Ages that representations of the flesh became a real object of technical study which would occupy artists as much as their commentators for centuries. The flesh became more complex in the *Duecento* with the application of a *verdaccio* base [2] on which was applied other layers to give the illusion of volume. From the 14th century, the complexions produced by superimposing layers of colors, sometimes transparent (glaze), had a finesse never obtained until then (Laneyrie-Dagen, 2006), reaching a striking realism in the works of artists such as Jan Van Eyck (Fig. 1) or Raphael. Still in the Middle Ages, *tempera* emerged alongside the encaustic technique which had endured since Antiquity, becoming the majority technique. It allowed painters to widen their palette by diluting the pigments in different glue or egg-based solutions. The *tempera* technique was supplanted by oil painting at the end of the Middle Ages (around 1500), which allowed painters to obtain the most beautiful flesh in the history of painting (Magnain, 2009).

Fig. 1. Van Eyck J. (1435) Madonna of Chancellor Rolin. Oil on panel, 66 × 62 cm. Paris, Musée du Louvre (1271). Photo: The York Project, via Wikimedia Commons (CC 0).

Fig. 2. Lagrenée L.-J.-F. (1767) Mercury, Herse and Aglauros. Oil on canvas, 55 × 70 cm. Stockholm, Nationalmuseum (NM 839). Photo: Bodil Beckman/ Stockholm Nationalmuseum (CC PD).

The exact color of the flesh color in painting remains difficult to define. It actually corresponds to a wide spectrum of shades, often clearer on representations of women (Frost, 2010), more or less reddish depending on the emotional state of the character (embarrassment, anger, etc.). Several treatises on medieval pictorial techniques offered a wide variety of recipes with multiple mixtures based on green, blue, ocher, white and red, making it possible to imitate the flesh colors (e.g. Cennini, c.1390/1859). However, cinnabar red and whitewash are commonly used in these recipes, i.e. shades of pink (red mixed with white) (Gettens, Feller and Chase, 1972).

At the end of the Quattrocento, flesh color was called incarnato (from the Latin carne, "flesh") and assimilated to red. Incarnato later gave the color term "incarnate" which Diderot used to describe the color of blood that shines through the skin of the characters in an oil on canvas by Louis-Jean-François Lagrenée (Fig. 2) (Diderot, 1876). The incarnate evokes indeed the blood which circulates under the skin and which tints it by transparency, as "under the blow of a categorical imperative of the in-between: between surface and depth" (Didi-Huberman, 2008). The French lexicographer Annie Mollard-Desfour does not succeed in precisely determining the shade corresponding to the French term incarnat (incarnate): she classifies it in her dictionary of red as "more or less bright red" (Mollard-Desfour, 2009), but also in that of pink, describing it as a "bright pink" (Mollard-Desfour, 2002).

3. An explanation about Pink as a Flesh Color

The skin is physiologically made up of several layers (epidermis, dermis, hypodermis), bearing each specific structural and chemical properties, but also their own color. The complexion perceived by our visual apparatus then results from the superposition of these layers perceived through transparency. Physicist Caroline Magnain has established a relationship between the dermatological structure of the skin and the pictorial representations of Caucasian skin tone, by analogy between the superposition of skin tissues and the layers of matter deposited on the canvas (Magnain, 2009). Hegel also pointed out that the color of the flesh in painting reflects the different colors of the organic layers of the body: the transparent yellow of the skin, the red of the arteries, and the blue of the veins, to which are added gray, brown and green tones (Hegel, 1848). Thus, this even apply with abstract works. The pink monochromes of the American painter Marcia Hafif (Roman Paintings, 1986) are spectroscopically similar to real skin, due to the superimpositions of successive layers of pigments (red, blue, and yellow) taking up the stratified biological structure of the skin (Magnain, 2009).

There is therefore a biological reason for the multiple visual representations of white skin by pink shades in Western artistic and cultural productions. However, even if we intend to exclusively restrict our focus on white skin,

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this only outline that all skin tones do not have the same color. Accordingly, painters have thoroughly criticized the shades of "flesh color" offered by the merchants of colors for being too pink to be able to account for the entire white complexions (Magnain, 2009).

The sampling carried out on images answering the keywords "flesh color" and "nude color" collected on the internets allows identifying shades corresponding to the flesh color nowadays [3]. Such methodology obviously has many limitations, such as the restriction to digital images or the subjectivity in determining the main color of each image. Nevertheless, the point is not as much to define what is flesh color or nude, but more to circumscribe a non-exhaustive set of colors corresponding to the effective uses of these designations. Moreover, the collecting of digital images that this methodology implies seems appropriate, since the designation "flesh color" is nowadays mainly used in fashion (especially underwear) and cosmetics (no photograph of painting is included in the sample) [4]. This analysis thus shows that the flesh (or nude) color corresponds to a wide spectrum of shades, which includes a certain amount of pink or pinkish shades, but also a lot of brown, orange, yellow and gray ones (Fig. 3; Fig. 4). We observe also a simplification of numerous skin tones to the single term "flesh color" (which is often describes as pink), analogous to the simplification of people with Caucasian complexions to the single designation "white people" (who are anything but white).
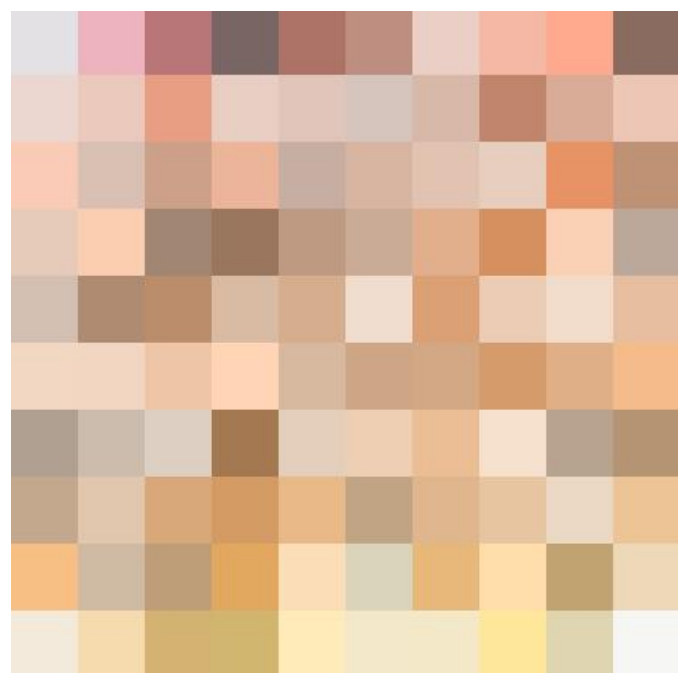
Fig. 3. Color chart obtained from the collection of hundred pictures answering the keywords "flesh color" on the internets. January 2020. Photo: K. Bideaux (CC BY-NC-ND).
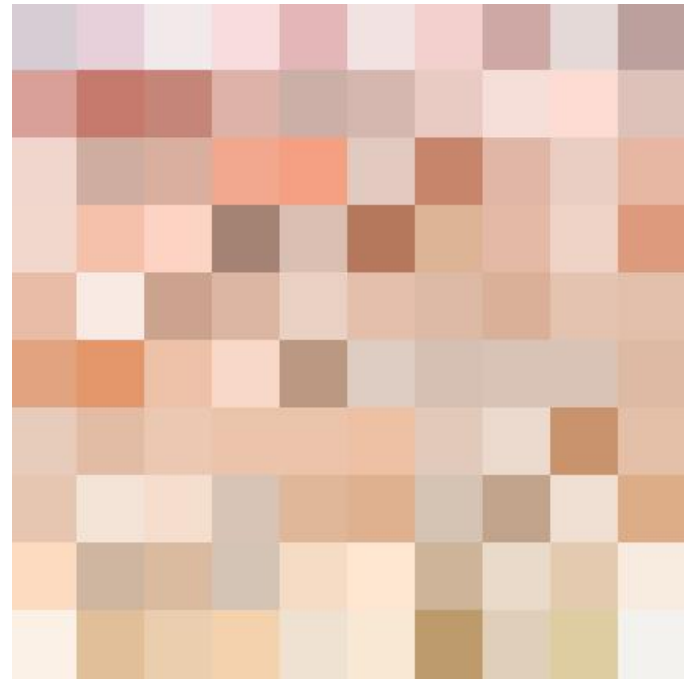
Fig. 4. Color chart obtained from the collection of hundred pictures answering the keywords "nude color" on the internets. January 2020. Photo: K. Bideaux (CC BY-NC-ND).

4. Flesh color, Race and Whiteness

The existence as well as the recurring use of a single term to designate all complexions, leads me to question flesh color in articulation with the concept of race. Skin color has indeed always participated in the construction of individual and collective identities, related to the racial system of classification of individuals according to their complexion (Blanchard, Boëtsch and Chevé, 2008). Mechthild Fend specifies that it is no coincidence that the term "skin color" appeared in the second half of the 18th century simultaneously in theory of French art and racial anthropology: both discourses grant the symbolical and social superiority of white skin as the universal ideal and standard of beauty (Fend, 2005).

White skin has indeed been associated since Antiquity with beauty — especially the female one (Pelletier-Michaud, 2016) —, and youngness (Garo, 2008). It is still deemed as a beauty ideal to be reached in black African communities (Emeriau, 2009). The blushing skin of embarrassed white women has also become a means for painters to bring eroticism to their canvas, also linking white skin to desire and sexuality (Fig. 5).

In addition, the history of Western art is also ethnocentric: critics and institutional exhibitions or acquisitions visibilizes the production of Caucasian artists, who themselves have mainly represented Caucasian characters (Fernandez-Sacco, 2001). Furthermore, when non-white people were depicted in paintings, they have

historically been portrayed through a racial and colonial perspective (Lafont, 2019; Lewis, 1996).

Fig. 5. Honthorst (van) G. (1625) Smiling Girl, a Courtesan, Holding an Obscene Image. Oil on canvas, 81,3 × 64,1 cm. Saint-Louis, Saint-Louis Art Museum (63:1954). Photo: Saint-Louis Art Museum (CC 0).

Whiteness not only dominates in the field of representations, but also gives the impression that it is a norm. This last element would explain why the color term "flesh" was constructed only on the color of white people, given that they represent a majority or even universal model. We can therefore say that the flesh color has a relationship with whiteness, a concept that designates the white social, cultural and political hegemony faced by ethno-racial minorities, as well as a mode of problematizing social relations of race (Garner, 2007). Using flesh color in cultural and artistic productions, as well as considering that everyone has the same complexion, *i.e.* a white one, could be consequently considered as a symbolic violence (Bourdieu and Passeron, 1970) for non-white people. This enduring vision still allows the maintenance of an unequal hierarchy based on race, by incorporating social, cultural and aesthetic classifications according to skin color. The French anti-racist activist Rokhaya Diallo recalled for

example that pink-beige color of sticking plasters, as well as the "nude" trend in fashion, was designed for the comfort of white people. These plaster indeed matches their skin color, while they are extremely visible on black skins (Diallo, 2018).

5. Flesh Color as "Human being" symbol

Sometimes, pink used as skin color by contemporary artists can bear a symbolic dimension, which is dissociated — at least in part — from the strict representation of the skin. It is a question of transmitting the idea of flesh/skin, and of associating a precise symbolism with it. For example, the impasto of colored plaster by the Italian artist Ettore Spalletti are mineral and powdery, and at the same time give an impression of life through a play of depth and subtle nuances. His work shows the rendering of the flesh that only oil usually does. Spalletti himself rightly referred to the skin when talking about his work, stressing the link between the pigment and dermatological variations: "pink has no fixity: it is the pigment of the skin that changes according to our moods" (Boudier, 2018).

As many previous studies have shown, colors and emotions are indeed linked (Simmons, 2011; Clarke and Costal, 2008): theorist of affects Brian Massumi explains that colors are capable of directly affecting the body, "[r]eflexively (that is to say, non-reflectively) in an immediate nervous response" (Massumi, 2005). The skin is therefore an interface between the inside and the outside, at the intersection of the Self and the Other and thus becoming a field of expression, experimentation and confrontation (Dagognet, 1998). In the film *Pieles* (2017), the Spanish director Eduardo Casanova follows in their intimacy several protagonists with bodies considered to be out of the ordinary [5]. The movie explores various themes such as desire, reification, discrimination, rejection or the search for authenticity. The skin in hinted by the title, and the omnipresence of pink in the decorations, costumes and visuals of communication works as a way of symbolizing skin as a metaphor for emotions and intimacy..

The use of pink as the color of the flesh can therefore signify the affects and emotions that pass through the flesh/skin. Flesh thus becomes a concept that artists use as a symbol and no longer for the purpose of representing the skin as an organic part of the body. Pink in the work of French artist Yves Klein particularly embodies a highly accomplished conceptualization of flesh. If he is mainly known for his ultramarine blue monochromes, he has however also produced numerous pink monochromes (named *Monopinks*) evoking the skin.

Klein's pink refers to material world, in opposition to the immateriality of the blue. The flesh is thus thought not in terms of corporality, as making direct reference to the body and its organicity, but to the flesh as a concept. It refers to materiality perceived as an experience, not as a form (Morineau, 2006), echoing the Maurice Merleau-Ponty's concept of flesh, thought ontologically as an extension of the body, as a part of the world (1979). Other artists such as the French Marguerite Humeau (exhibition *FOXP2* at Palais de Tokyo, Paris, 2016) [6] or the Austrian Pamela Rosenkranz (installation *Our Product*, 2015) [7] have developed this same discourse by using pink as a symbol of the flesh, understood as a common material shared by all human beings. In short, these artists refer to pink as a symbol of life and humanity.

This close association between pink (as the very color of flesh) and human being as a whole was also the grounds on which the esoteric anthroposophical current based its theory. Its creator, Rudolf Steiner, did not strictly write a theory of colors. He nevertheless proposed to assign a meaning to each colors, understood as representing the forces in action in nature: green as the color of plants, white that of light, black that of darkness and the peach-blossom color (*Pfirsichblütfarbe*) that of the human soul. Among them, peach-blossom is a shade of pink that Steiner described with reference to the "color of human flesh, which of course is not exactly the same for different people", admitting therefore that pink cannot signify all skin tones (Steiner, 1921/2010). However, can we really disconnect the flesh color as a symbol of humanity, from the flesh color representation of white bodies? English artist Derek Jarman wondered whether Steiner would have chosen the color of the peach blossom as the color of human existence if he himself had been a black man (Jarman, 1994/2003). We could indeed wonder if the pink flesh as being able to designate the whole of humanity would not have to do with the whiteness of those who make this association (as a reminder, Klein, Humeau and Rosenkranz are also white people).

6. Pink as "organic flesh" color

Perhaps it is necessary to think of the flesh not as indicating the color of the skin, but rather as indicating to what lies below: the muscles and organs, or even the mucous. The art historian Dominique Grisard said for example about the series *Second Skin* (2017) of the Swiss artist Nici Jost that "[p]ink is both skin-deep and flesh and blood" (Grisard, 2019). The artist herself says that pink is a color of "equality and unification" because no matter the skin color, size, ethnicity or gender, our

mucous are all the same color (Jost, 2016). However, if the mucous, certain organs or certain meats can effectively be pink or considered as pink colored, it is more the red, which represents our organic interiority: that of the blood coloring the muscles, flowing when the body is opened or injured. Even when the flesh thought as subcutaneous organic matter is represented in pink, the red of the blood is always intrinsically associated with it, both visually and symbolically (Salamandra, 2018).

7. Conclusion

This analysis of the connotations associated with the color flesh reveals the way in which the relations of power (here of race) between dominant and dominated are involved in the history of colors as well as enrich their symbolism. If the use of pink as flesh color in the representations of white bodies corresponds to a logic (admittedly simplified) of transcription of reality, its use as a symbol of complexion *in general* is more problematic. Flesh color is effectively part of a racial perspective, shaped by history and social representations, which we cannot ignore. Similarly, while pink can signify flesh considered as what is common to human existence, it cannot claim any meaning of universality because its symbolic construction is anchored in a white Western art history. This is not to say that artists, theorists or even marketers are racist, but more to contextualize our symbolic systems, the way we deploy them — in particular through color —, and their real effects on individuals.

The ambition of this article was to propose a transmedia and transhistorical vision of the uses of the "flesh color" in the art and the Western culture. The conciseness of the paper's format has forced me to proceed to a synthesis of the examples presented and to a simplification of the analyses. Additional investigations are therefore necessary in order to highlight the variations in the use of flesh color, according to the periods, the geographical areas, but also according to the support.

Acknowledgment

Short biography of the author

Kévin Bideaux is PhD candidate in arts and gender studies at the Laboratoire d'études de genre et sexualité (LEGS, UMR 8238, University of Paris 8). His doctoral research focuses on a better understanding of the uses of pink in the visual arts, marketing, sciences and politics. He is also a visual artist, working essentially with the color pink.

Notes

[1] This includes black people, but also those sometimes referred to as "brown people", a term that refers to people from the Middle East, North Africa and the Indian subcontinent.

[2] *Verdaccio* is a mixture of black, white, and yellow pigments resulting in a grayish or yellowish soft greenish brown.

[3] I used the methodology used by Kate Hughes and Donna Wyatt to determine the nuances associated with breast cancer (Hughes and Wyatt, 2015). This involves determining skin tones from a sample of digital images collected from internets, responding to a specific keyword. I collected about a hundred unique images responding to the keywords "flesh color" and "nude color" (identified using the Google image search engine), I then determined in each image the significant shade of flesh using an image editing software, and I finally classified each of these shades according to its hue (H), its saturation (S), and its value (V), the HSV model being particularly relevant when it comes to digital images. After having carried out this sampling work, I gathered and condensed all the shades obtained into two hundred-color charts.

[4] These images are most often disseminated on the Internet by commercial sites or photographs of haute-couture shows or celebrities.

[5] A young woman born without eyes is a prostitute to support herself, and counts among her clients an obese woman who lives her lesbianism in secret. A pregnant dwarf is the exploited star of a children's show in which she plays a pink bear. A woman with a deformed face is in a relationship with a man whose skin has suffered severe burns; another young woman has a deformity that has caused her mouth and anus to be inverted. One last character is an exception: a teenager with an able body who dreams of losing his legs to become a mermaid.

[6] For this exhibition, Humeau created white sculptures in the shape of elephants, which she arranged on a pink carpet. The carpet was made especially for the exhibition, from a recipe developed by the artist using the chemical components of a human being (carbon, oxygen, sulphur, calcium, etc.), of which she respects the percentages and quantities (Santa Lucia, 2016).

[7] This installation consists of an impressive basin filled with two hundred and forty thousand liters of a pinkish-colored liquid. The color chosen by Rosenkranz is based on the standard colors of cosmetic industry foundations, which are understood from their shades to be mainly designed for whites people only (Launay, 2015).

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Geometric models for color perception

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ABSTRACT

In 1962 and 1974, respectively H. Yilmaz and H.L. Resnikoff published two groundbreaking articles about color perception, which were ignored by the scientific community. Yilmaz showed the striking analogy between Lorentz transformations and the modification of color perception under illuminant changes. On the other hand, Resnikoff, using mathematical techniques coming from theoretical physics, studied the possible geometrical representations of a homogeneous space of perceived colors, i.e. a space in which all the elements have "the same importance". Both works come up to the same conclusion: the structure of the space of perceived colors can be better characterized through hyperbolic geometry, while usual color spaces have a Euclidean structure. In this work, we show how a modern revision of these important articles allows us to highlight a correlation between the colorimetric attributes and some objects of special relativity theory and quantum mechanics, opening innovative perspectives in the theoretical comprehension of perceptual phenomena related to human chromatic vision. A remarkable result of this new formalism concerns the retinal chromatic encoding expressed by the sum of an achromatic signal and two opponent chromatic signals (typically called red-green and yellow-blue). This looks as an intrinsic description of a so-called "color state", in contrast to what happens in natural image statistics, where such an encoding is not an intrinsic result of the theory, but it is obtained through a principal component analysis.

1. Introduction

The scope of this paper is to give a brief and simple overview, with dissemination purposes, about a novel program of formalization of colorimetry in which both geometry and techniques typically used in mathematical physics play a fundamental role. Due to space limitations, and in order to keep the storytelling as simple as possible, we will leave many details to open access references that the interested reader may wish to consult.

2. Yilmaz's relativistic model

The value of Yilmaz's work (Yilmaz, 1962) lies in the interpretation of color perception as a relativistic phenomenon. Indeed, as Einstein showed up that space and time are relative to the single inertial observers (i.e. observers moving with constant speed with respect to each other), in the same way Yilmaz states that the colors perceived by an observer adapted to a certain broadband illuminant are relative to it. Thence it is possible to use the mathematical tools typical of Einstein's special relativity theory to model color perception. On one hand this opens new paths for a deeper comprehension of what is a color space and which are the most suitable coordinates to identify a perceived color, on the other hand it provides a mathematical formalization of the space's transformations under changes of the broadband illuminant to which the observer is adapted. This last aspect makes Yilmaz's model easy to adapt for applicative purposes, in particular for color correction of digital images.

2.1. The coordinates

As it is well-known from (Wyszecki and Stiles, 1982), there are strong physiological and psychophysical reasons behind the statement that the space of perceived colors is a 3-dimensional cone.

Thence every perceived color can be univocally identified by three coordinates. The wide range of color spaces proposed for digital and industrial applications clearly shows that the choice of these three parameters is far from being trivial.

For Yilmaz, a trichromatic observer adapted to a certain illuminant I is able to identify the colors he/she perceives by two chromatic coordinates and an achromatic one.

Let us fix three orthogonal axes, depicted in Fig. 1. The origin of the three axes corresponds to black, denoted by K, on each axis there is the value associated to a certain coordinate. Let us call these three coordinates α, β and γ.

Fig. 1. Axes α, β, γ.
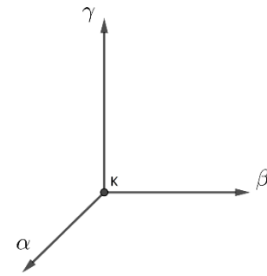
The achromatic coordinate γ goes from black to white, through a grayscale, while the chromatic coordinates belong to the plane α, β (we will call it chromaticity plane) shown in Fig. 2. The first chromatic coordinate is the angle ϕ, called hue, the second one is the radial coordinate ρ, called chroma.
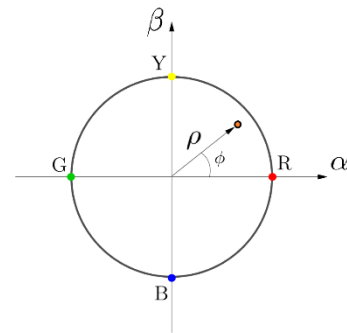

Fig. 2. Chromaticity plane.

The axes α and β represent respectively the hue oppositions red-green and blue-yellow, proposed for the first time by Hering. The existence of these two oppositions is the reason why it is impossible to perceive e.g. a reddish green or a yellowish blue. In this paper, we will follow the simplified Yilmaz framework in which well-known perceptual effects that show interdepencence between chromatic attributes are ignored. As a consequence, the space in which we will work has cylindrical shape, see Fig. 3. Using the coordinates α and β is mathematically equivalent to using the coordinates ϕ and ρ, but perceptually less immediate.

A colorimetric attribute of fundamental importance, dependent to the ones defined above, is the saturation σ. It denotes the purity level of a color and it is defined as the ratio between chroma and the achromatic coordinate σ = ρ / γ. The existence of a maximal perceivable saturation (i.e. a maximum attainable degree of purity that a perceived color can have) leads us to the exclusion of the points of the cylinder that do not belong to the cone of slope ∑ depicted in Fig. 4.
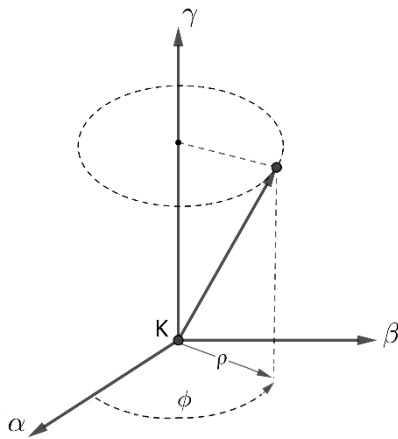
Fig. 3. Cylindrical coordinates.

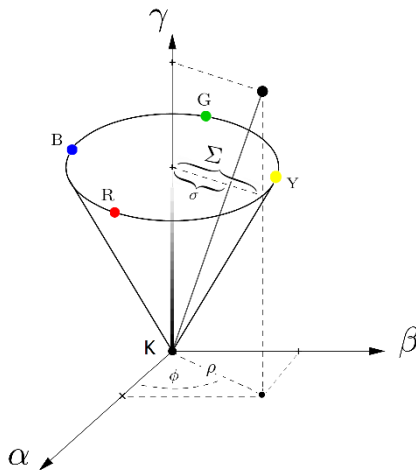*Fig. 4. Cone of perceived colors. Note that, when* γ=1, *we have that σ = ρ.*

The perception of a stimulus constituted by a monochromatic light (e.g. a red laser) will have maximal purity, hence saturation ∑.

2.2. *The two rooms experiments*

Yilmaz motivates the introduction of relativistic concepts in a colorimetric framework through three experiments. It must be stressed that Yilmaz did not give quantitative data nor apparatus description for his experiments, thus, a doubt about the fact that they have actually been implemented still remains.

Let us consider two different broadband illuminants, we will denote them by I and I'. Let us call α, β, γ (α', β', γ', respectively) the coordinates that an observer adapted to I

(to I' respectively) associates to the stimuli that he/she perceives. Yilmaz's aim is to show how the coordinates α, β, γ are transformed into the coordinates α', β', γ'.

Let us suppose we have two adjacent rooms completely painted in white. In each room, different kinds of light sources can be posed. The two rooms are separated by a wall with a tiny hole through which an observer placed in the first room is able to perceive light stimuli posed in the second room and vice-versa. Hence the presence of the hole allows the observer to perceive light stimuli belonging to an environment to which he/she is not adapted.

A piece of white paper is divided into two parts, each of them is posed in one of the two rooms. We are going to introduce just the two more emblematic experiments.

Experiment 1: the perception of white is relative
In this first experiment, depicted in Fig. 5, I is placed in the first room and I' in the second one. In a first phase the observer is placed in the first room and adapted to I. He/she perceives the piece of white paper placed in his/her same room as white; while the other half, placed in the second room and enlightened by I', has greenish hue and small saturation σ.

The second phase of the experiment is identical, but the roles of the two rooms are inverted: the observer is placed in the second room and adapted to I'. He/she perceives the piece of white paper placed in the room with him/her as white, while the other one, posed in the first room is perceived as having reddish hue and the same small saturation σ.
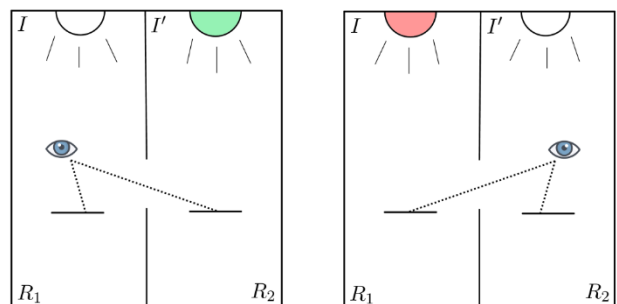

Fig. 5. Experiment 1.

Experiment 2: the invariance of the spectral red
In the second room is placed a monochromatic red light source, while the first room is enlightened by I in a first phase and by I' in a second phase. In both phases the observer is placed in the first room and adapted to the broadband illuminant enlightening it. He/she observes that, in both cases, the piece of white paper, posed in the second room and illuminated by the red laser, is perceived as having the same red hue and the same maximal saturation ∑, see Fig. 6.

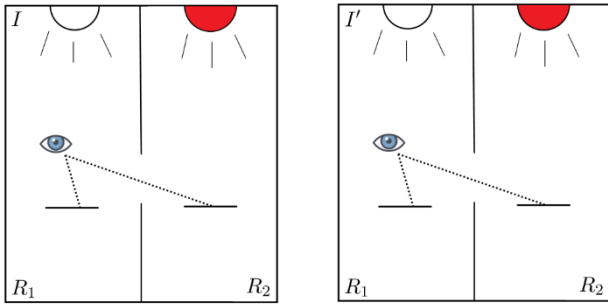*Fig. 6. Experiment 2.*

Formalizing the information given by the three experiments, the coordinate transformation (linear in the variables α, β, γ) that Yilmaz obtained is the following:

$$\begin{cases} \alpha' = \frac{\alpha - \sigma\gamma}{\sqrt{1 - (\sigma/\Sigma)^2}} \\ \beta' = \beta \\ \gamma' = \frac{\gamma - (\sigma/\Sigma^2)\alpha}{\sqrt{1 - (\sigma/\Sigma)^2}} \end{cases}$$

The details needed to understand how to arrive to this kind of transformations are available in (Prencipe et al., 2020). In the same paper, the reader can find the description of the third Yilmaz experiment, which is more involved to discuss and not relevant for the present paper.

2.3. *Parallelisms with relativity*

The "relativistic jump" is attained recognizing in the transformation written above a so-called Lorentz boost, which allows us to find relativistic analogues for all the quantities mentioned up to now.

In the theory of special relativity, the measure of space and time is relative to the observer, hence every observer has his/her own coordinate system with respect to which he/she can measure space and time. In the simplest case of inertial observers, i.e. observers moving with constant speed with respect to each other, the transformations converting the coordinates of one observer into the coordinates of another one, are the Lorentz boosts. Thence an observer adapted to a broadband illuminant corresponds to an inertial observer in special relativity theory.

Consequently, there will be parallelisms between space-time coordinates and the coordinates of the perceptual space described in subsection 2.1. In particular, the achromatic coordinate γ corresponds to time, while the chromatic coordinates α, β (or, equivalently, ϕ and ρ) are the analogous of a two-dimensional physical space.

From the definition of saturation as σ = ρ / γ, it is easy to deduce its relativistic analogue. Indeed, it should be a ratio between a spatial and a temporal quantity, so a constant velocity. The maximum perceivable saturation Σ

corresponds to the maximum attainable velocity, i.e. the speed of light c. As a consequence of this, it is clear that Yilmaz's second experiment is nothing but a colorimetric reinterpretation of the fundamental principle of special relativity theory stating that light speed is the same for all inertial observers. For further details see (Prencipe et al., 2020).

3. Resnikoff's model and its quantum reinterpretation

As we have seen in section 1, Yilmaz's model introduces in the context of color perception analysis concepts and tools typical of special relativity theory. In this second section, we will see how Resnikoff's model allows us to see in color perception a quantum phenomenon.

Resnikoff's article (Resnikoff, 1974), gone almost unnoticed by the scientific community as Yilmaz's one, is an extraordinary (and rare) example of something that we could call "theoretical psychophysics", because he used the typical flow of thinking and mathematical techniques of theoretical physics, but applying them to the concept of perceived color, i.e. a psychophysical attribute.

More precisely, he started his analysis from the so-called Schrödinger's axioms (Schrödinger, 1920), adding a further fundamental one: the homogeneity axiom, and determining mathematically which geometric structures satisfy all the axioms. Notice that the pattern followed by Resnikoff, which characterizes the works of modern theoretical physics, is substantially different from a mere procedure of selection by interpolation, that is a work of minimization of the discrepancies with the experimental data.

Resnikoff showed that only two geometric structures are compatible with Schrödinger's axioms and his homogeneity axiom: the first one is the canonical Helmholtz-Stiles space that has many different practical expressions like LMS, RGB, XYZ, etc. all of them geometrically equivalent; the second one is a hyperbolic structure totally new in color theory. It is exactly this last one that allows a quantum interpretation, as we will detail in the following.

3.1. *The axiomatic construction of a homogeneous color space*

Erwin Schrödinger, well known for his works in quantum mechanics, dedicated many years of his scientific career to the study of color. In 1920 he wrote a series of very elegant works summarizing in a mathematically coherent framework the main results concerning color obtained by scientists like Newton, Grassmann, Maxwell and Helmholtz.

Schrödinger's axioms can be summarized stating that the space of perceived colors of trichromatic observes has the geometric structure of a convex regular cone of dimension 3.

The fact that the space of perceived colors is a cone means that a positive multiple of a perceived color (i.e. a brighter version of the color) is still a perceived color (note that this is an idealization, because the phenomenon of saturation of the photoreceptors implies that the cone is not infinite, but truncated at the glare threshold). The convexity property means that, inside the cone, the segment joining any couple of perceived colors is made up by perceived colors (this was proved by Grassmann). Regularity is a technical property that can be translated into practical terms into the statement that the cone of perceived colors has a vertex corresponding to black. Finally, the dimension of the cone is a consequence of the existence of 3 kinds of retinal cones which start the chain of neural events leading to color vision.

Resnikoff, starting from the observation that no color is "special" with respect to the others and that, thanks to the well-known phenomenon of chromatic induction, it is possible to modify the perception of any chromatic stimulus just embedding it in an appropriate background, came to the conclusion that the following postulate holds: the space of perceived colors is locally homogeneous, that is it exists an invertible transformation which maps any color to any "sufficiently similar" other color.

It can be easily proven that this postulate, justified by the induction phenomenon, together with the convexity of the cone, implies its global homogeneity, which is exactly the mathematical property characterizing the spaces where no point is special because we can pass from one point to any other one through an invertible transformation. This is the reason of the choice of adjective "homogeneous".

In summary, putting together Resnikoff's axiom and Schrödinger's ones, we can conclude that the space of perceived colors has the structure of a convex regular and homogeneous cone of dimension 3. There are only two kinds of cones of dimension 3 satisfying all these properties: the first, and the simplest one, let us denote it by P', is the set of all the nonnegative real numbers Cartesian to itself three times, which is exactly the Helmholtz-Stiles space, canonically used in colorimetry. The second one, more complex and interesting, denoted by P", is given by the Cartesian product of the set of positive real numbers and a hyperbolic space which can be characterized in many different ways, some of them are easy to visualize, like the hyperboloid embedded in the real three-dimensional space, the upper-half plane or the Poincaré disk (i.e. the open unit disk in the real

plane), others are more abstract, like, for example the space of the real symmetric positive-definite 2x2 matrices having determinant equal to 1 or the quotient space SL(2,R)/SO(2). For more details see (Provenzi, 2020).

In the following subsection, we are going to show that this second space is the most interesting one from a theoretical point of view and for the consequences related to the quantum interpretation of color vision.

3.2. *Jordan algebras and the link with quantum mechanics*

In the articles (Berthier and Provenzi 2019; Berthier, 2020) a fact of fundamental importance is stressed: the so-called classification theorem of Jordan-von Neumann-Wigner states that the two structures found by Resnikoff for the space of perceived colors coincide exactly with the only two possible forms of a symmetric cone of dimension 3, where a cone is said to be symmetric if it is convex, regular, homogeneous, open and self-dual (a technical property which is not important to explicit here).

Moreover, Koecher-Vinberg theorem states that every symmetric cone is the so-called positive cone of a (formally real) Jordan algebra.

Without going into many specialized and complicated details of the theory of Jordan algebras, which will result to be merely notional, we just say that a Jordan algebra is a vector space endowed with a commutative, but not associative product called the Jordan product and that the Jordan algebra whose positive cone is P" is the algebra A of the real symmetric 2x2 matrices with the Jordan product between two matrices A and B of A defined as: A∘B=(AB+BA)/2.

Jordan algebras have a privileged role in the modern quantum theories, where the objects are the quantum observables of a system, in duality with their quantum states. Once again, an exhaustive treatment of these concepts should deserve much more space, see e.g. (Berthier and Provenzi, 2021), hence we just underline that it is the lack of associativity of the Jordan algebra that gives a quantum character to the description of the observables and the states of the system.

To make the theoretical ideas exposed up to now more concrete, let us now talk about a feature of this quantum model for color perception that we consider particularly meaningful. It is the fact that it is possible to represent, in a very natural way, a color state through the superposition of three so-called density matrices, indicated with $\rho(r,\vartheta)$, (i.e. positive definite and with unit trace) which represent an achromatic state and two states of chromatic opponencies red-green and yellow-blue, respectively, as expressed in the following formula:

$$\rho(r,\theta) = \rho_0 + \frac{r\cos\theta}{2}[\rho(1,0) - \rho(1,\pi)] + \frac{r\sin\theta}{2}[\rho(1,0) - \rho(1,\pi)].$$

This kind of description, perfectly coherent with the human color vision, as remarked in section 1, is obtained in the quantum model just passing to a parametrization in polar coordinates of the density matrices.

The color encoding performed by the human visual system comes out in a very natural way in the framework of the quantum model and there is no need to resort to an analysis "a-posteriori", like it is done in the context of natural image statistics, where it is shown that the principal components of a wide dataset of natural images coincide with the triplet given by the achromatic axis and two chromatic axes having opponent colors.

4. Conclusions

The power of Yilmaz's work lies in the fact that he gave the foundations to construct a relativistic theory of color perception. Clearly here we exposed just some of the possible aspects of special relativity theory translated in the colorimetric context. The analogies between the two theories are much more, and they hide questions deserving further and deeper investigations in the colorimetric context. Furthermore, there are numerous aspects that are well suited to immediate and concrete applications. Let us imagine we have a picture taken by a digital device which is not able to automatically adapt, like a human being, to the illuminant of the scene we want to capture. We can imagine that the uncorrected image as a light stimulus posed in the second room in Yilmaz's first experiment, with an observer posed in the first room. Indeed, it corresponds to a perception devoid of adaptation, that can be easily corrected applying a suitable Lorentz boost.

As regards Resnikoff's work, we can say that the theoretical clarity and the lucidity of his work have been crowned, after more than 40 years after its publication, by a surprising interpretation: color perception is well suited to be naturally described by the algebraic formalism of quantum theories.

In summary, the two "forgotten" articles of Yilmaz and Resnikoff, clearly posed the bases of a quantum-relativistic color theory capable of explaining into deep and mathematically rigorous terms the phenomena of human chromatic perception. Moreover, they add a further step towards the use of hyperbolic geometry in colorimetry as also mentioned by several other authors, e.g. (Farup 2014 and Lenz et al. 2005).

8. Short biography of the authors

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The red of Lina and Oscar

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ABSTRACT

The article gives a brief history of modernist architects Lina Bo Bardi and Oscar Niemeyer and tries, through a bibliographic review and visual analysis, to identify meanings, analyze the generated spatiality and understand the impact caused by the repetitive and striking use of the red color. To do so, a brief history of the color red and how it was mastered, perceived, and appropriated by humans over the centuries is traced, and, finally, three essential projects of each architect are analyzed. We conclude narratives for the reds of Lina and Oscar, who go through the communist history of the characters, visual indications, and the theory of functionalism.

1. Modern Brazilian Architecture

According to Lúcio Costa (1902 –1998), modernism in Brazil is justified by the affirmation of the identity of our culture and representing the "spirit of the time." For Oba (2014), this movement, which prioritized function, caused Brazilian architects much interest. The French-Swiss architect Le Corbusier had a significant influence on the formation of modern thought in Brazilian architects. The discussion about modern issues gained substantial prominence in Brazil after the constant migratory movements in the post-war period, whether from Brazilians who returned after studying abroad or from foreigners looking for an opportunity outside Europe in crisis.

It is important to note that not only did the European crisis repel professionals, but the condition of Brazil attracted them. Cavalcanti (2001 apud Lobato, 2009) states that good economic conditions, the government's will to establish a new face for the federal capital, and a generation of revolutionary intellectuals and architects made modern Brazilian architecture a reality. With the new republic, the change in the bases of production of national wealth and the migration of the status of Brazil from an agrarian to an emerging country creates a demand for buildings that represent this recent phase of the country. These works were mainly from the government of Getúlio Vargas (1930-1945), which had as one of its priorities the construction of buildings to house government agencies of the new administration (Cavalcanti 2001 cited Lobato, 2009).

Among the various possibilities for discussing the use of color in this historical-cultural context, two Brazilian architects were selected for a more careful look at this article due to the recognized influence in the unfolding of the issues opened by the avant-garde. The works analyzed, both three examples of Lina Bo Bardi as three of Oscar Niemeyer have a marked cultural nature. In addition to the programs themselves, such a characteristic is manifested in the condition of manifestos about what architecture is, which this type of order allows. In this sense, party issues are displayed more clearly, making it possible to investigate the meanings of design actions and how the definition of red, present in all the works to be analyzed, contributes to the creation of the architectural discourse of each architect.

1.1. Lina Bo Bardi

The architect was born on 5 Dec. 1914 in Rome, Italy. She graduated in architecture from the Faculty of Architecture of the University of Rome. After graduating, she moved to Milan, where, after working for Gio Ponti, she became the editor of the magazine Quaderni di Domus. During the Second World War, she founded with Bruno Zaevi the publication A-Cultura dela Vita and is a member of the Italian Communist Party. In 1946, she married the journalist and art critic Pedro M. Bardi (1909-1999), and, in that same year, they left for Brazil, where she was naturalized in 1951.

Initially, she lived in Rio de Janeiro-RJ, then the country's capital, where she had the opportunity to expand her influences and knowledge of the new country. However, when she moved to São Paulo (SP) - after Pietro was invited to found and direct the Museum of Art of Sao Paulo Assis Chateaubriand - MASP - Lina turns icon of modern Brazilian architecture. In 1950 Lina founded Habitat magazine - an important cultural vehicle that included art, architecture, design, cinema, theater, music, photography. In 1951 she built her residence - the Glass House - which is currently the headquarters of the Instituto Lina Bo e P. M. Bardi. In 1957 construction began on the new MASP headquarters - Lina's first project that will be analyzed in the article - in 1959, "she is invited by the governor of Bahia to direct the Museum of Modern Art of Bahia (MAM-BA)" (Instituto Bardi, 2020), in the same year she restores Solar do Unhão - second project analyzed in the article. In 1977, the third project analyzed in this article began to be constructed - the Centro de Lazer Sesc - Fábrica Pompéia in São Paulo (SP).

1.2 Oscar Niemeyer

Oscar Niemeyer was a Brazilian, born in Rio de Janeiro-RJ on 15 Dec. 1907. He studied at the National School of Fine Arts (now the Federal University of Rio de Janeiro). In his third year, he interns with Lúcio Costa - a future urban planner responsible for the new national capital Brasília (1960). Lúcio Costa was invited, in 1936, by the then Minister of Education Gustavo Capanema to design the new headquarters of the Ministry of Education and Health. Lúcio brings together a group of young architects; Lúcio still insists that Le Corbusier be invited as a consultant. Despite not inviting Oscar from the beginning, he ends up calling him. In this way, Oscar contributes to the project that is considered one of the foremost modern Brazilian architectural landmarks, the Gustavo Capanema Palace. After that, Oscar falls in the graces of important figures - as the best example, we have the governor of the state of Minas Gerais, Brazil's future president and founder of Brasilia, Juscelino Kubitschek. Oscar lived 104 years and worked until the last years of his life, resulting in a vast collection of works, drawings, and sketches. In 2003, nine years before his death, he was asked to design his first building in Britain as part of a Serpentine Gallery action devising the third work analyzed in this article.

2. The Red

According to Michel Pastoureau (2017), red was the first color that humans dominated, manufactured, reproduced, and discovered different tones, first in painting and later in the dye. According to the same author, this also explains why in some languages, the same word means "red," "beautiful," and "colorful." Le Corbusier (Serra Llunch, 2013) agreed and guaranteed that red affirmed its presence. One of the primary colors is considered a warm color (Argan, 1992) and has been widely used with mastery by great artists such as Pietro Mondrian, Vassili Kandinsky, Marc Chagal, Ellsworth Kelly, and Mark Rothko.

Outside the artistic field, the color red is also very representative. According to Klein (2018), red has been a symbol of power and government since antiquity permeating the Middle Ages; it was worn by Roman emperors, popes, and European sovereigns. During the French Revolution, a movement that, according to some authors, inaugurates the Contemporary Age, the Jacobins, and sans-culottes as identification dressed in a red cap. During the 20th century, the color red was adopted by communist movements, workers, and socialist movements, in the sense of fraternity. In this context, the color was also associated with the hope of a better life, as well as with blood and suffering.

2.1 Museum of Art of São Paulo – São Paulo, São Paulo – Brazil

The Museum of Art of São Paulo was founded in 1947 by Assis Chateaubriand (1892-1968), businessman and patron of São Paulo. The first modern museum in the country was directed by the Italian critic and dealer Pietro Maria Bardi, Lina's husband. Initially, it worked on one floor of a business building and moved to the current location in 1968. The location of the building itself is iconic, situated on the most famous avenue in the country's financial capital; it is still under the intersection of another avenue. The landmark of the history of 20th-century architecture is based on the use of concrete and glass. Its 74-meter span has always been a geographical reference and meeting point.

The four massive pillars that support the volume above this span and the beams that make up this structural effort are bright red. Although, since the beginning of the sketches, the red color appeared and, according to Miyoshi (2006), it was an old idea for Lina to use the color, initially, the beams had no color; they were in apparent concrete without any aesthetic treatment. In the 1990s, to solve an infiltration problem, a company donated products "for the protection of exposed concrete against deterioration" (Miyoshi, 2006, p. 143). The color

chosen by Lina is fire-fighter red (fig.1); in addition to transforming the building into a "cultural event" (Miyoshi, 2006, p. 143), the proposal aimed to encourage the use of paints that fled white or ice accounted for 70% of national consumption (Miyoshi, 2006).

On the floors below the span, there are two stair-ramps also in red (fig.2). The proposal made by Lina Bo Bardi, in this sense, reserves the use of red in two distinct functions, structure and circulation. The red elements bring common the desire to signal, point out, and distinguish the elements put in color. Architecture should be understood as a set of elements articulated throughout but with their particularities.

Fig. 1 – MASP, (KON, N.)

Fig. 2 – Stair-ramps. (KON, N.)

2.2 The Solar do Unhão – Salvador Bahia, Brazil

Upon receiving the invitation to direct the Museum of Modern Art, Lina stayed in Salvador, Bahia, between 1959 and 1964, where she found another face of Brazilian identity, the African face. The museum is

located in Solar do Unhão, an existing building that needed to be restored and adapted to receive such a program. Due to her experience in post-World War II Italy, Lina applies critical restoration to the set of buildings (Cerávolo, 2010, p. 219). The use of the color red in the external frames (fig. 3) was not agreed with heritage agencies; Cerávolo (2010) states that the colors of the facades and frames would be specified later after submission to the National Heritage agency. Finally, the choice of red color did not pass through the appreciation of Organs responsible agencies; Azevedo (1963 apud CERÁVOLO, 2010, p. 234) characterizes this and other choices as a "loss for the monument."

In the Solar do Unhão project, what can be perceived is the use of red as a signaling act with intentionality close to the use of color in the MASP project. The architect with her choice reveals her look at the historical construction processes belonging to the work involved, the difference between the brick-built in masonry, and the openings treated in wood. By observing the set, one can learn the difference between the fixed parts and the moving parts, employing colors, enabling many other inferences about the architectural qualities.

Fig. 3. Solar do Unhão's Entrance. . (Kon, N.)

2.3 Sesc Pompéia – São Paulo, São Paulo – Brazil

Lina was invited in 1977 by Renato Requeixa and Gláucia Amaral, then directors of the SESC - Social Service of Commerce, to transform the Mauser Brothers' old drums factory into a leisure center. The project develops over nine years with the help of students and recent graduates (Ferraz, 2008). The new public facility should promote social harmony, cultural production, and the social welfare of the city's population. With the addition of two large exposed concrete prisms to the original set, the project gained prominence, the blocks receiving sports equipment were inaugurated in 1986.

The apertures of the lower block have an amoeboid form, while in the more massive block, they are square but do not follow orthogonal alignment. In both buildings, the openings are closed in red wooden trellis (fig. 4). In addition to the use of red in the frames, several installations, such as air ducts, truss fittings, handrails, throughout the complex, which a priori should go unnoticed, become red and stand out in the landscape.
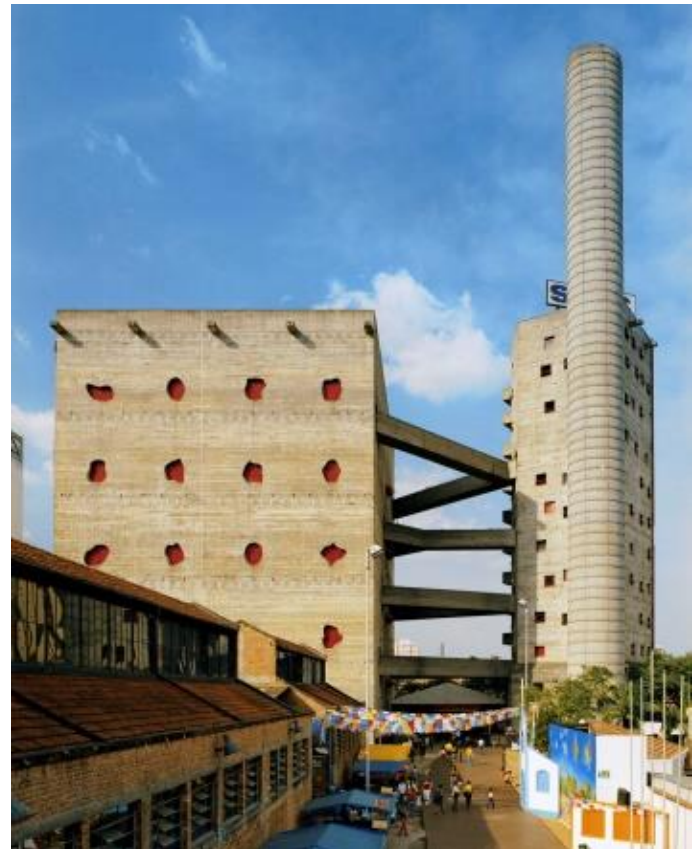

Fig. 4. Sport blocks - Sesc Pompéia. (Kon, N.)

The Sesc Pompéia project reveals the coherence of the architect's plastic research. An intention in the sports blocks is very close to that seen at Solar do Unhão. Despite different situations, the same desire is to signal and differentiate between fixed, open, and mobile openings. The amoeboid shape in one block, and the misalignment, in the other block reveals the constructive possibilities of concrete as much as the rhythm and alignment reveal the limits of masonry in the Solar.

2.4 Museum of Contemporary Art of Niterói (MAC), Niterói, Rio de Janeiro – Brazil

The museum on the banks of Guanabara Bay in Niterói was designed in collaboration with structural engineer Bruno Contarini. Completed in 1996, the cylinder blooms like a flower composing the landscape for which it is also a viewpoint. Its circular shape includes a large glass opening

that allows visitors to the museum to appreciate all the natural beauty that surrounds it. With its main body at 16 meters high, access is via a winding concrete ramp that allows visitors to appreciate the landscape and the building itself on a 98-meter long architectural promenade full of changing perspectives. The invitation and marking of the ramp take place through its red fire floor, a plastic decision to highlight the access of the large white volume (fig. 5).

Fig. 5. Museum of Contemporary Art (Leonardo Finotti In: SEGRE, 2010)

Fig.6 Main facade with access ramp – (Modern Architecture London)

2.5 Serpentine Gallery Summer Pavilion – London, United Kingdom

The Serpentine Gallery pavilion aims to give visibility to architects who do not yet have a project in the UK, so the talent of the professional can be shared and appreciated by a new audience strolling through Hyde Park. The pavilion is part of an annual event produced by the gallery that performs its assembly at the beginning of the London summer and is dismantled at the end of the

same season (Allen, 2018). For 21 years, this annual event has featured projects by great architects, and in 2003 it was Oscar Niemeyer's turn.

With clear traces of modernism, it was "built-in concrete, painted white and accessed by a ramp" (Doroteo, 2016). A synthesis of significant elements of the architect's best-known projects, a grand gesture of drawing, loose from the terrain, unfolds in a single direction and generates the spatiality of the ensemble. This gesture is presented in white, being emphasized at the entrance by a void, built away from the closings, and accessed by a ramp with a red cover (fig 6), and at the back by a red plane.

2.6 Auditorium – Ibirapuera – São Paulo, São Paulo – Brazil

Conceived by the then governor of the state of São Paulo, José Pires do Rio, the park that would be modeled after great European examples such as Hyde Park in London or Boi de Boulogne in Paris. Parque do Ibirapuera occupies a total of 157,000 m² and was only opened in 1954 due to the drainage problem that the land presented. The problem was solved by the then official Manequinho Lopes, who decided to plant hundreds of Australian eucalyptus on the ground to drain the water in the region.

Fig.7. Ibirapuera Auditorium (Kon, N.)

Oscar Niemeyer designed the buildings that make up the park's infrastructure, and Burle Marx should run landscaping, but the latter was not executed. The park's program has various equipment such as temporary exhibition spaces, museums, auditoriums, lakes, and planetariums. Despite the vast program here, we will analyze only the auditorium. Initially, the building was not completed and was only completed in 2005, almost 50 years after the park opened. The auditorium is a trapezoid with its entrance marked by a red marquee (fig.7),

nicknamed Flint (Dudeque, 2009). In addition to the punctual presence at the entrance, the back of the auditorium (which is reversible) (fig. 8), the large opening door of the stage is also a large red rectangle that strongly marks the white prism.

Fig.8. Ibirapuera Auditorium Back Door (Kon, N.)

Oscar Niemeyer adopts a very controlled color/material palette that uses only white, red, and wood. White is reserved for opaque surfaces built, while the wood is for the handrail and some acoustic coverings. Red is highlighted not for a specific function but for accompanying the user/spectator through their experience in the auditorium spaces. First, it signals the entrance unequivocally with the marquee and immediately welcomes the route along the internal ramp (fig. 9) to the audience spaces through the floor covering. It would be a matter of signaling, as in the previous cases. However, the experiential issue is highlighted when it is emphasized when inviting Tomie Otake to make a sculpture in red. The artist's occupation of the wall and ceiling radiate throughout the space through the reflection of color. Red expands its signaling and didactic function to become the poetic accent of the proposal.

Fig.9. Intern Ramp – Ibirapuera Auditorium (Kon, N.)

3. Conclusion

The secure connection of the two architects, Lina and Oscar, with the premise of modern architecture remained faithful to the attention to the functionalism typical of the avant-garde of the beginning of the 20th century. The red of Lina and Oscar may have had different origins; they are in sympathy with communism and in the certainty of marking their projects with vivid and exquisite colors. Kandinsky's theories fostered this avant-garde by attributing spiritual qualities to very few geometric elements and colors; for him, for example, "red is extremely immobile by a restless color, vivacious and active ... immense and almost inconsequential force" (Luz, 2014, p.214). The perceptual intensity of the red is adopted by the two architects, analyzed here, as a cognitive resource to signal what architecture is built on. Lina Bo Bardi's case, with a strong emphasis on the tectonic issues of the work in its plastic dimension through a didactic approach, is one of the ways she found of forming the critical conscience of modern man. In the case of Oscar Niemeyer, this social function emphasizes this social awareness due to its poetic dimension through the valorization of the experience of color. The two architects fixed themselves in the collective imagination as irreverent, bold, and brilliant; undoubtedly, they pictorially red-marked both histories.

4. Conflict of interest declaration

The authors declare that nothing affected their objectivity or independence and original work. Therefore, no conflict of interest exists.

5. Funding source declaration

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The Changes of Transparent Colours in Being Laid upon Others': Considerations for a New Perception of Glazes with Historical Pigments and Dyes

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ABSTRACT

This article describes a reconstruction of 40 sequences of historical glazes used by most European schools of painters from the 15th to the 18th century. Its main objective is to visually document the appearance of colours overlaid with historical pigments and dyes, which have often suffered from a degree of deterioration that renders it difficult to determine their original appearance. We also seek to show the extent to which the historical glazes and overlays can alter our perception of the underlying colour. To this end, lab tests and sources have been used with the aim of suggesting a series of sequences of colour overlays that were widely used in the aforementioned period, so as to reproduce them on a canvas using historical pigments and colours agglutinated in oil, in accordance with the main painting techniques of the era studied.

The Changes of Transparent Colours in Being Laid upon Others': Considerations for a New Perception of Glazes with Historical Pigments and Dyes

1. Introduction

Until the 16th century, artists followed the Flemish style of producing paintings with a finely glazed appearance, excellent for painting on panels, with several very thin layers of colour interacting with each other, and very rarely using monochrome finishes comprised of a single layer of paint. This approach suggests the need for a different view of the history of oil painting techniques, whose base problem should be considered not in terms of invention or individual discovery (as Giorgio Vasari has accustomed us to think) but in relation to a long evolutionary process that is documented in the treatise attributed to Theophilus Presbyter (Del Vescovo, 2013: 244-255). Painting technique remained unchanged even when painters began turning to canvas as a support medium, and it was only between the late 16th and early 17th century that European paintings acquired a more full-bodied appearance. However, glazes continued to be widely used as a technical solution right through to the 19th century, when new trends fuelled the quest for different visual effects, created with thicker brush-strokes. This development was related to the development of industrial colours, much thicker and more opaque, which also dried more quickly and offered a wider palette of colours. Glazes began to lose their practical purpose because colour modulation was no longer such a popular technique and although it has continued to be used up to the present day, its application in the 19th century was in fact uncommon. The term 'glazing' appeared for the first time in the treatise *On the True Precepts of the Art of Painting* by Giovanni Battista Armenini (1587), although, as will be discussed below, the concept dates back further.

Other authors, such as Francisco Pacheco and Antonio Palomino, referred to this practice as '*baños*' ('bathing'). It is not easy to define exactly what a glaze is: the term designates any translucent or transparent layer of colour placed over a lower layer with the intention of changing the underlying colour, or of giving it a new hue, in order to darken, brighten, or intensify the saturation or to form a compound colour. Until the 19th century, the relatively limited nature of the palette necessitated the use of effects of chromatic transparency that could produce more complex tones than those offered by pigments used individually. In reality, rather than glazes, it was common practice to use colour overlays. It is important to remember that the painting technique of overlaying colours was a practice typical of the panel painting of the late Gothic period, as documented in Chapter LXXXIX of Cennini's *Il Libro dell'Arte*. That same chapter also contains an interesting passage about the process of painting in oil being too slow and dull, a point made previously by Theophilus. In Chapter XXV of *De diversis*

artibus (Hawthorne, J. et al. 1979, [s. XII]) he provides instructions on this painting method '[...] *whenever you have laid on the pigment, you cannot lay a second over in until the first has dried out. This process is an excessively long and tedious one in the case of figures* [...]') [1], which is expanded on in the following chapters up to Chapter XXVII, where he describes the process of 'translucent' painting.

Three centuries later, Leonardo da Vinci (1817 [s. XVI]) [2], in Chapter CCL of his *A Treatise on Painting*, would discuss the phenomenon of colour overlay, or '[...] *the changes of transparent colours in being laid upon others of different kind* [...]', which inspired the title of this article.

Most of the pigments available on the palette from the 15th to the 18th century were translucent to a certain extent, especially when applied thinly, and more translucent still are dyes, which become lake pigments when they are precipitated on an inorganic substrate such as rock alum, calcium carbonate or sodium carbonate. The use of lake pigments applied over pigments was much more common than is generally believed; moreover, it was essential to the development of a whole range of tones that made it possible to blur the colour and expand the chromatic possibilities (Thompson, 1956; Bruquetas, 2003; Herrero-Cortell, 2019).

2. Materials and Methods

The main purpose of this article is to reconstruct some of the main sequences of glazes made from pigments and lake pigments, as practised by Europe's main schools of painting from the 15th to the 18th century, based on paint stratigraphies (which are not included here due to space limitations) and historical sources. Due to the relatively rapid degradation of many of these materials, the appearance of the colour can change dramatically over time: the yellowing of oils and darkening of varnishes that tend to occur with these mixtures, as well as other factors like the degradation of dyes and pigments, low stability to light and other environmental parameters, mean that the colours rarely look as they originally did (Zalbidea, 2014: 33-37). For example, there are well-known cases of colour instability that have been found in works by painters like Lorenzo Monaco (ca. 1407), such as the *Coronation of the Virgin*, preserved at the National Gallery in London, the *Coronation of the Virgin* at the Uffizi Gallery of Florence, and the *Coronation* at the Courtauld in London (Burnstock, 1988).

This article has three specific objectives:

1.	To reconstruct a palette of colours with glazes that cannot be observed today due to the effect of the

degradation factors mentioned above. This reconstruction has involved the use of historical pigments and dyes that are largely obsolete today.

2. To highlight how glazes or overlays of these translucent materials are able to alter the viewer's perception of the underlying colours.

3. To provide a set of standards for future spectroscopic and multi-band imaging studies in the form of the test strips processed for this study.

The performance of this study required the application of 40 sequences documented in written sources and stratigraphies. Most of the pigments used to produce the test strips were provided by the company Kremer, although some pigments, such as saffron, reseda and kermes, have been developed using traditional recipes, fixing the dye with rock alum in cases that so required. The pigments used were: smalt (10000); azurite (10204); natural ultramarine, from lapis lazuli (10510); indigo (36007); vermilion (42000); minium (42500); English red deep (40545); laccifer lacca carmine (lac dye) (36020); rose madder; cochineal; Italian gold ochre (40220); orpiment (10800); Naples yellow, based on lead antimony (10130); reseda lake, prepared by hand according to traditional recipes; saffron lake; green earth (40810); natural malachite (10300); verdigris (44450); and sap green (37391).

Although it is a short list, the choice of products was based on their importance and distribution, which is why some materials used only in very specific locations and periods, such as orchilla, have been omitted.
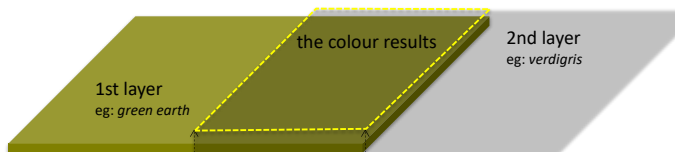
Fig. 1. The colours were arranged according to the diagram. The colour results interacting with the colour from the two layers. Eg: A second layer of verdigris was applied over a first layer of green earth.

Various overlays of glazed colours were applied, ordered by hue: blue, yellow, red, green, a second green obtained by mixing yellow and blue, purple colours obtained by mixing red and blue pigments. Both the pigments and the lakes were agglutinated in linseed oil, ground with a porphyry stone and applied to the test strip so that the base colour, the colour of the glaze and the colour resulting from the overlay could all be viewed individually and simultaneously (Fig. 1). The support medium was a linen cloth prepared first with natural glue (as a "primer coating"), followed by four additional layers of primer comprised of glue and calcium sulphate hemihydrate. The test strips were photographed with a Nikon D800 camera and colour card, with colour and white balance correction using an AIC card.

3. Results and discussion

3.1. *Blue*

The traditional blue pigments are not very opaque and were often used for glazes. In tempera painting it was common to apply them with glue over a layer of red earth, as documented and confirmed by stratigraphic studies of mural painting up to the 15th century in both Italy and Spain. Painters often worked to create glazes with these blues, a practice that Pacheco adamantly condemned, except when the overlays were made with ultramarine: 'I do not endorse bathed blues, unless made with ultramarine' [3] (Pacheco, 1649: 392). Years later, Antonio Palomino would specify that ultramarine blue*: 'is used in two ways; either bathed or fashioned out of any of the other blues already made'* [4] (Palomino, 1947 [1715]: 501).

Smalt is a colour preferably used *al fresco*, but due to the sensitivity of its tone and its characteristic transparency as a result of its vitreous nature it was greatly valued for making glazes in oil as it has a more vivid tone than azurite. Tempering was also done with oil and varnish (Price, 2017: 135-154), although their blackening or yellowing tendencies were well known, due to effects derived from crushing the particles and because their index of refraction is very similar to that of oil used as a binding agent (Döerner, 1998: 69).

The use of smalt blue over azurite (Fig. 2. Sample 1) was common in the 16th and 17th centuries, although its introduction to the colour palette is identified by Bensi (1980: 33-47) as being around 1470-80. Its presence in layers has been documented in the Veneto region, and also among some Spanish baroque painters. The choice of two inorganic blues on a palette is certainly not commonplace, but as smalt is more vivid than azurite and even more transparent, it was sometimes used to give the blue a more saturated tone. For example, in his treatise Pacheco (1649) attests to the use of these two pigments together, although not as glazes.

It was much more common for azurite to be covered by ultramarine lapis lazuli (Fig. 2, sample 2). In fact, as it was slightly opaque and particularly expensive, ultramarine was reserved for the final layer of glaze. This is how the Portuguese painter Felipe Nuñez explains it in his treatise of 1615.

It was clearly a widespread practice to apply lapis lazuli over azurite or another blue, as can be found in numerous stratigraphies showing one or more azurite or even smalt layers under the ultramarine layer, and it is also recommended in Théodore Turquet de Mayerne's treatise in 1620 (Fels, D. 2010: 141).

Prussian blue on top of azurite (Fig. 2, sample 3) was similarly used, but this blend was much less common and was largely limited to the 18th century. Prussian blue is dark by nature and it was therefore used to give greater depth to the azurite, especially when the latter was less pure or more greyish, or for the purpose of shading.

Indigo is a dye that was used widely in painting from the 14th through to the 19th century, although it has not received the attention it deserves. It was an economical solution when more expensive blue pigments could not be obtained (Herrero-Cortell, 2019: 13-15). Indigo of European origin was known as woad (even it was not pure woad, but a mixture [*guado puro o misto a travertino*], according to Brunello, 1975: 194) and the Asian dye was known as woad indigo. In both cases, its main dye is the same and its colour was identified with the term '*indigo'*. Its use added to other blue pigments to enhance them was documented by Eraclius in *De coloribus et artibus Romanorum*: [...] *Shade azure with indigo, lay on the lights with white lead* [...] (Merryfield, 1967: 257) [5].

Both lapis lazuli over indigo (Fig. 2, sample 4) and indigo over lapis lazuli (Fig. 2, sample 7) are used in shaded areas, for example in the folds of clothes. Lapis lazuli with black changes to dark grey, and the only way to give it depth and sheen without making it opaque is to add woad or indigo. This combination, which was already commonplace in medieval painting, continued to be used until the 16th century.

In his treatise, Palomino explains how the blue movement needed to be darkened with woad (indigo): '[...] *having to be fashioned, its tints of clear, and dark, can be blended in, mixing in proportion with the lead white in walnut oil, and enhancing the strong darks with the indigo.*' [6] (Palomino, 1947 [1715]: 501).

Even Pacheco mentions this custom, although with reference to azurite (Fig. 2, sample 5). Like indigo used with smalt to add shade to the vibrant tone of this blue (Fig. 2, sample 6), a very common solution in the 16th century in the painting schools of Spain and Northern Italy, such as the Venetian school, was to use both smalt and indigo to create these finishes. Indeed, the Padua manuscript (written in Venice around 1580) reads: '[...] *Blue azure with indigo, lay on the lights with white lead* [...]' [7] (Merryfield, 1967: 657).
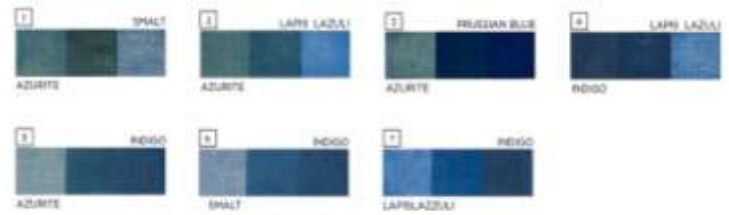
Fig. 2. Blue samples. 1) Smalt over azurite; 2) Lapis lazuli over azurite; 3; Prussian blue over azurite; 4) Lapis lazuli over indigo; 5) Indigo over azurite; 6) Indigo over smalt; 7) Indigo over lapis lazuli

3.2. *Yellow*

The use of lake pigments and inks for yellow glazes was a very common practice in painting and is mentioned constantly in the treatises. In very rare cases stratigraphy reveals that yellows were made with pigments, given their high covering power. Yellow lakes (saffron, reseda and sap green) suffer considerably from deterioration and are highly unstable to light, making them difficult to recognise. For this study we chose to use lead antimony (commonly known as Naples yellow), which was often included on the palettes of 16th-century painters, lacking the option to use lead-tin yellow (*giollorino* or *giallolino zaldolino*, as it was known in Italy, while in France it was known as massicot; it is often confused with Naples yellow or antimony yellow), which was used as a base colour until the 17th century.

Saffron is one of the dyes most frequently found in recipes, associated with the colour change in the crushing and mixing stage, although it could be applied in glaze form to deepen or saturate the tone of other yellows on a lower layer (Fig. 3, samples 8, 10, 12), like reseda (Fig. 3, samples 9, 11, 13). Both saffron and ochre are mentioned in the late-14th century by Cennini, who, with respect to saffron, observed: *Do not expose it to the open air, for it soon loses its color* [...] (Ch. XLIX) [8]; however, it is a direct dye (that does not need a mordant) that was used frequently, as Palomino attested.

With respect to reseda (known in Spanish as *ancorca*), Palomino observes: '*Greenish-yellows are made by beginning the clear with lead-tin yellow, and adding ancorca to the second dye [...] and after it is dry, it is bathed in ancorca, and dried, and touching the clears with giollorino, where suitable, and squeezing the darks with the shade, leaving an excellent yellow.*' [9] (Palomino, 1947 [1715]: 50). This practice varied from region to region; for example, in northern Europe it was more common to use *stil de grain* yellow, which was sometimes referred to with the name Dutch pink. In 1620, Théodore Turquet de Mayerne wrote of '[...] *massicot shaded off with Dutch pink* [...]' (Fels. 2010: 141).

Finally, we considered the overlaying of Naples yellow ochre and orpiment (Fig. 3, samples 14-15), two pigments that are relatively opaque but that appear in stratigraphies in a preliminary application of ochre.
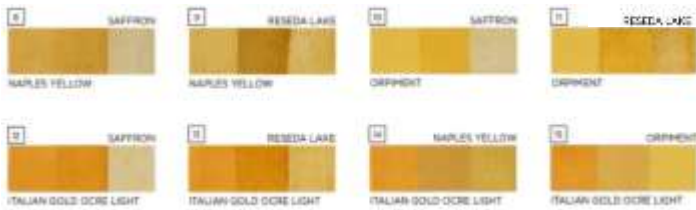

Fig. 3. Yellow samples. 8) saffron obver naples yellow; 9) reseda over naples yellow; 10) saffron over orpiment; 11) reseda over orpiment; 12) saffron over ochre; 13) reseda over ochre; 14) naples yellow over ochre; 15 orpiment over ochre.

3.3. *Red*

Cinnabar/vermilion (mercury sulphide pigment) and minium (red lead), together with red earths, are historically the red pigments *par excellence*. None is known for being very translucent, although red lead and mercury sulphide pigments can produce this effect when used in thin layers; in fact, they have been used in this way over layers of very dark red earths, even in mural painting (Calabria et. al, 2019) (Fig. 4, samples 16-18). Most of these overlays have lead, applied both on top of red earth (Fig. 4, sample 17) and on top of cinnabar (Fig. 4, sample 18), creating a similar visual result. Cennini, for example, suggests that: *'If you would make a silk drapery either on panels or on walls, lay on the ground with cinnabar and lighten with minium, or if you like with sinopia, and lighten with giallorino on walls'* [10] (Cennini, 1971 [s. XIV]: Ch.CXLIV).

However, this overlay was less common than those done with red lake, the queen of the glazes in the red range. Red lake pigments were usually made with madder but dye lakes, Kerria lacca or Indian lake (lac dye) and, to a lesser extent, kermes, known as the European cochineal, were also used (Herrero-Cortell, 2019). The application of lake pigments as glazes over layers of inorganic reds was widespread, although occasionally they formed localised glazes. In his treatise, Da Vinci specifies the following procedure: *'[…] to make a fine green take green and mix it with bitumen and you will make the shadows darker. Then, for lighter [shades] green with yellow ochre, and for still lighter green with yellow, and for the high lights pure yellow; then mix green and turmeric together and glaze every thing with it […].'* [11] (Da Vinci, The Notebooks: Ch. IX).

The hues of the lake pigments are varied and may cover a wide spectrum of reds depending on the method they were processed with and also on the colourant used. Madder lake covers the widest spectrum of reds, ranging from a pink-orange to a violet red, and including carmine, deep red and maroon. The lake sequence over cinnabar/vermilion was used constantly from the 14th through to the 19th century; it is among the most cited in the literature and probably one of the most frequently found in stratigraphies (Fig. 4, sample 19-21). All over Europe in the 14th and 15th centuries it was common to add a little of saffron when tempering minium or vermilion to give them a warmer hue, since they sometimes could look quite cold (Thompson, 1956: 108). A madder lake glaze applied over minium was also very common, resulting in a deep red-orange colour (Fig. 4, samples 22-23). Under the lake glaze there is often a mixture of several reds (such as vermilion, minium and lake) and white lead, as the underlying combinations of lakes are often the pink tones resulting from the same lake mixed with white lead (Fig. 4, samples 24-25). Thus, for example, in his treatise Théodore Turquet de Mayerne suggests: '[…] *[Take] lake and white, and if you want, glaze with lake. The work will be very beautiful. [Or] lake, vermilion and white. You can glaze it with lake* […]' (Fels, 2010: 14).
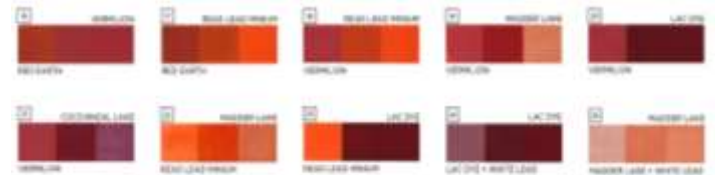

Fig. 4. Red samples. 16) vermilion over red earth; 17) red lead over red earth; 18) red lead over vermilion; 19; madder lake over vermilion; 20) lac dye over vermilion; 21) cocchineal lake over vermilion; 22) madder lake over red lead; 23) lac dye over red lead; 24) lac dye over a misture of lac dye with white lead; 25) madder lake over a mixture of madder lake and lead white.

3.4. *Green*

Due to their transparent nature, greens were used a great deal as glazes, in one or more layers over a *grisaille* in black and white, as recommended, for example, by Pacheco, who maintains that: '[…] some [greens] are fashioned with black and white in oil and then bathed in ground verdigris with linseed oil' (Pacheco, 1990 [1649]: 484) [12].

The use of verdigris with varnish (which itself produces an amber colour), or of copper resinate, is well documented throughout the literature, including the

writings of Armenini (1587: 126) and De Mayerne (Fels, 2010: 139, 142), according to the precept appearing in the Brussels manuscript: '[…] *To make very beautiful green for glazing, verdigris must be used with varnish*' [13] (Merrifield, 1967: 812). But verdigris was not the only pigment that could be used for this purpose: many green earths, for example, are highly transparent when tempered with oil, but their tone is not generally either saturated or vivid (Döerner, 1998: 75). Sometimes they were used as glazes over other colours, such as ochre or Sienna, indigo or a *grisaille* modulated over black, as recommended by Palomino (1988: 505), and they often served as a base for a glaze with a different green or yellow. When malachite is overlaid, the tone is also more consistent, and tends to have more body (Fig. 5, sample 26). These stratified layers were commonplace and are documented in painting: a cheaper pigment, like earth, was applied under a more expensive one, like malachite, which is quite transparent. It was more common to use verdigris or copper resin for glazes over green earth and then to apply malachite over that, thereby producing darker and deeper tones (Fig. 5, samples 27, 30). In some cases an organic green could be used, such as sap green, which is translucent like other lakes, although it has a brownish and less vivid tone, which is why most writers did not consider it to be among the 'noble' colours.
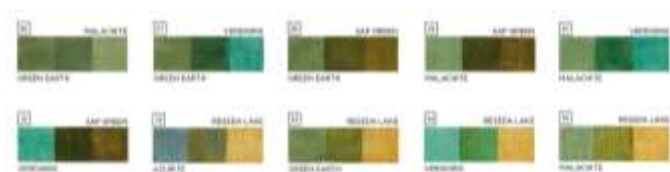
Fig. 5. Green samples. 26) Malachite over green earth; 27) verdigris on green earth; 28) sap green ver green earth; 29) sap green over malachite; 30) verdigris over malachite; 31) sap green over verdigris; 32) reseda lake over azurite; 33) reseda lake over green earth; 34) reseda lake over verdigris; 35) reseda lake over malachite.

In other cases, green was produced by overlaying a yellow (always in the form of a lake) on a preceding green or blue like azurite (Fig. 5, sample 32), as recommended by Eraclius: '[…] *If you wish to make a colour like lily green, mix azure with white lead; shade it with azure; lay on the lights with white lead; and when it is dry, cover it over with clear saffron* […]' [14]. (Merrifield, 1967: 257). Indeed, the addition of yellow dyes to verdigris to make a colour that was less cold is a constant in the literature. There are numerous recipes for verdigris, including, for example, the addition of reseda or saffron while crushing and preparing the mixture, or even making

a verdigris blend with certain dyes to apply the final glaze, as recommended by Da Vinci: '[...] *then mix green and turmeric together and glaze every thing with it* [...]. (Da Vinci, The Notebooks: Ch. IX) [15]. He recommends the same with saffron, unless it becomes discoloured quickly, and with yellow from aloe: '[...] *Supposing the Verdigris has already been used, and the part finished, you may then glaze it thinly with this dissolved Aloe, and it will produce a very fine colour* [...].' [16] (Da Vinci, 1817, [16th century], Ch. CCXXIX). The greying tendency of verdigris can be definitively corrected by adding a yellow lake pigment, which results in a deeper and more saturated colour (Fig. 5, sample 34), although it is common for yellow lakes to appear over other greens (Fig. 5, samples 33-35).

3.5. *Purple*

Traditionally associated with dyes, purple is a compound colour, although some purples can be made using a violet lake pigment, such as orchilla or cochineal, over a grisaille base (Fig. 6, sample 37). Orchilla is a material rarely mentioned in the treatises, although Palomino (1947 [1715]: 1164) decided to include it in the list that appears at the end of his treatise containing the most commonly found colours on the painter's palette. Most of the purples used were mixtures of a pigment and a blue or red dye, or overlays of glazes created with a transparent blue or red, as recommended by Théodore Turquet de Mayerne: 'Purple is made with smalt and lake […]' (Fels. 2010, 141).

Indeed, the best violet tones are obtained by mixing or overlaying red lake over smalt or lapis lazuli (Fig. 6, samples 38-40), according to a practice previously described by Cennini (1971 [s. XIV]: Ch. LXXIII).

Fig. 6. Purple samples. 36) Cocchineal lake over indigo;

37) cochineal lkake over a misxture of such lake with white lead; 38) cochineal lake over smalt; 39) cochineal lake over azurite; 40) cochineal lake over lapis lazuli

4. Conclusions

What colours would we see if we entered the studio of an artist from the past who had just finished a painting? What did the colours look like before the oil or varnishes

altered the appearance of the paint with their natural oxidation? And how would they look if they had never undergone the (sometimes aggressive) cleaning processes they were subjected to?

This article has presented a reflection on the artistic literature, in the form of treatises, which provide very few guidelines for the reproduction of the recipes, but which document workshop practices that have provided the information needed to reconstruct 40 colour overlays made with pigments and dyes, agglutinated with linseed oil used as a medium for the glazes. The picture this provides is immediate: it not only offers a kind of baseline, but also facilitates a much-needed reflection on which glazes can actually change the colour tones and our perception of those colours.

5. Conflict of interest declaration

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

6. Funding source declaration

7. Acknowledgment

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Notes

[1] '[…] *Ac deinceps accipe colores quos impugner volueris, terens eos diligenter oleo sine aqua, et fac mixturas vultuum ac vestimentorum sicut superius aqua feceras* […].'

[2] *Quando un colore trasparente è sopra un altro colore variato da quello, si compone un color misto diverso da ciascuno de' semplici che lo compongono. […] E cosí il paonazzo dato sopra l'azzurro si fa di color di viola; e quando l'azzurro sarà dato sopra il giallo, egli si farà verde; ed il croco sopra il bianco fa giallo; ed il chiaro sopra l'oscurità fa azzurro, tanto piú bello, quanto il chiaro e l'oscuro saranno piú eccellenti.*

[3] Pacheco states: '*Los Azules bañados no los apruebo, si no es con ultramarino*'.

[4] Palomino states: '*se usa de él en dos maneras; o bañado, o labrado sobre cualquiera de los otros azules ya concluidos*'.

[5] The original text says: '[...] i*ndicum incides de lazurio, matizabis de albo plumbo* [...]'.

[6] Palomino states: '[…] *habiendo de ser labrado, se pueden ir metiendo sus tintas de claro, y obscuro, mezclándole, en proporción, con el albayalde de nueces, y ayudando los obscuros fuertes con el añil.*

[7] The original text says: '*Azurro (...), smaltino, e biadetto, s'ombrano con indico, laca e negro.'*

[8] Cennini states: '[...] *guardati non vegga l'aria, chè perde subito suo colore* [...]*'.*

[9] '*Los escarolados se hacen comenzando el claro con el génuli, y añadiéndole ancorca a la segunda tinta [...] y después de seco, le dan un baño de ancorca, y secante, y tocarle los claros con genulí, donde es conveniente, y apretarle los obscuros con la sombra, y queda un amarillo excelente*'

[10] Cennini states: '*Se vuoi fare drappo di seta, o in tavola o in muro, campeggia di cinabro, e pallia o ver vitica di minio; o vuoi di sinopia, e pallia di cinabro* [...]*'.*

[11] Leonardo da Vinci states: '*Per fare un rosso bello: togli cinabrese e mista con anguria arsa pell'ombre iscure, e pelle più chiara, matita e minio, poi vela con lacca bella* […]*.'*

[12] Pacheco states: '[…] *se labran algunos con blanco y negro a olio y después lo bañan con cardenillo molido con aceite de linaza*'.

[13] '*Pour faire de très beau verd galssé, faut employer le verdigris avec du verny* […].'

[14] The original text says: '*Si vis facere clorem similem gladio viridi, misce lazurium cum albo plulmbo, et quando fuerit siccus, coperi de claro croco* […].*'*

[15] Leonardo states: '[…] *di poi togli verde e curcuma insieme e vela sopr'ogni cosa*'.

[16] Leonardo states: '[…] *e se tu avessi finito un'opera con esso verde semplice, e poi sottilmente la velassi con esso aloe (risuluto in aqua), allora essa opera si farebbe di bellissimo colore* […]'.

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A test on color discrimination in complex scenes for a better comprehension of color blindness

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ABSTRACT

Today, in color vision and physiology, it is well known that the phenomenon of light transduction, operated by the retinal photoreceptors, cannot fully describe color perception. Color perception, in fact, is a complex phenomenon which involves not only the signal transduction in the human retina, but also the signal elaboration made by the visual cortex. For this reason, it is fundamental to consider color perception as a result of the interaction of all the colors, shapes, shadows and lights in a scene, thus of the scene spatial arrangement. In this work, we present the results of a preliminary experiment to investigate chromatic perception phenomena in spatial contexts. To perform this test, we selected five famous paintings and we asked to color blind (CB) and non-color blind (NCB) people to complete three tasks. In the first and second test, the paintings presented a missing piece. Here, the CB and NCB users had to select the correct paint missing piece among four patches with different chromatic values, at first isolated from the painting and then added in the artwork. In the third test the users had to identify the original artwork among a set of four images of the paint fully chromatically modified. Thanks to this experiment it has been possible to have a first preliminary evaluation on the role of the spatial context in color discrimination, and it has been possible to analyze some of the main limits in color blindness actual models.

KEYWORDS (color blindness, perception, visual system)

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1. Introduction

The phenomenon of vision is a complex process, and it is still not completely understood despite years of studies and modelling (Levin, et al., 2011). In the human eye, the retina is the sensible layer in which the nervous signals are generated in response to the visual stimuli coming from the surrounding environment. In the retina, the image of the visual world is focused and converted in electrical neural impulses, which are sent to the brain. The retina consists of several layers of neurons interconnected by synapses, and it is supported by an outer layer of pigmented epithelial cells. The primary light-sensing cells in the retina are the photo-receptor cells, which are of two types: rods and cones (Davson, 1990). The external part of photoreceptors is composed by a layer containing the photopigment, a chemical substance that isomerizes when absorbs light (Sharpe, et al., 1999). From this, the electric signal is generated as the first neural response to the visual stimuli, it is transmitted through the retina neural networks and it is processed by the visual cortex (Curcio, et al., 1990).

In this process of signal transduction and elaboration, the cones are the photoreceptors responsible for the photopic vision (e.g., daily vision) and for the ability to see colors. There are three kinds of cones, and each type contains a different pigment that absorbs in different percentage the radiations of the visible spectrum, and each cone contains just one of those pigments. Due to this, the cones can be classified in: Cones L that cover the region of long and medium wavelengths with a maximum at 560 nm; Cones M that absorb medium wavelengths with a maximum at 530 nm and Cones S that absorb shot wavelength with a maximum at 420 nm (Osterberg, 1935).

Color blindness (or color vision deficiency) is the decreased ability to see and distinguish colors. It is generally an inherited problem which affects the development of one or more type of cone cells. Color blindness affects mainly the male population (Nathan, 1999) and correlates also with the ethnicity (Brown & Lindsey, 2004). In general, in individuals of Northern European ancestry, the common form of red-green color blindness affects the 8% of men and just the 0.5% of women (Deeb, 2005). Color blindness can be divided in many categories, among them we focused on dichromacy (i.e., the state of having just two types of cones) and anomalous trichromacy (i.e., the state of having one of the three types of cones which behaves like one of the other two). Considering this subdivision, the kind of dichromacy or anomalous trichromacy can be classified depending on the absent (or anomalous) cone type in: protanopia (or protanomaly), deuteranopia (or deuteranomaly) and tritanopia (or tritanomaly).

Nowadays color blindness is studied and diagnosed mainly considering the retinal level of the visual path, because the problem originates from retinal anomalies. The many different color blindness tests, like the Pseudo-Isochromatic Plates (e.g., Ishihara test), the Nagel's anomaloscope, the CAD test, which have been found successful to diagnose this condition (Evans, et al., 2021), are all based on the retinal modelling of the color stimulus. However, this approach only considers the point-wise color formation, without any spatial mechanism. From the first experiments carried out by Von Helmholtz in the 19th Century and by Land (Land, 1959), (Land & McCann, 1971), Hubel (Hubel, 1995) and Wiesel (Hubel & Wiesel, 1998) in the 20th Century, it become clear that describing color vision processes as a mere transduction at retinal level of a point-wise stimulus, is not sufficient (Rizzi, 2021). Thus, current state of the art suggests color perception in carried out both at retinal and cortical level, since spatial mechanisms are a fundamental part of the robustness of our visual system and are at the base of its capabilities of adapting to widely varying visual conditions (McCann & Rizzi, 2011).

In this context, a recent series of preliminary studies investigated the role of spatial mechanisms in CB people, to assess how much the spatial arrangement affects color perception (Rizzi, et al., 2014, reprinted in Vol. 13, July 2015.), (Bonanomi, et al., 2017), (Eschbach & Nussbaum, 2021). This work follows the encouraging results evidenced by those recent studies and aims at preliminary analysis the roles of spatial arrangement and complex contexts in color perception of CB people.

Differently from other experiments, in this work, we used as test images five paintings from different periods, and we aimed at assessing how much the scene spatial arrangement of non-natural scenes may affect the color vision in NCB and CB people, considering the presence of edges and gradients in the scene. Thus, the main research question of this work is: Gradients and edges in a scene, can help CB people in identifying colors?

In this preliminary study we tested 30 subjects, of which 15 are Color Blind (CB), without focusing on the specific type of color deficiency. To this aim, in Section 2 a description of the experimental setup will be reported, explaining the three different perceptual experiments. Then, in in Section 3 we report the main experimental results, which are broadly discussed in Section 4.

2. Experimental setup

The experiment has been performed on 30 subjects, 15 CB and 15 NCB. The sample of CB people was composed by 13 males and 2 females, and the sample of NCB subjects was composed by 4 males and 11 females. In

both groups the average age was of 23 years old. In order to test a wide set of subjects, the test has been performed remotely on different devices such as tablets, computers, or smartphones, and all the tests have been performed anonymously. The test has been conducted using the web application Google Form (Google, 2021). Before the beginning of the test, we made a short survey asking to the participants for sex, age, and potential color blindness, we did not focus on the type of color blindness. In fact, since it was not possible to clinically diagnose the kind of color blindness which affected the users, in the initial form we just asked to the subjects if they know to be CB. In order to confirm the hypothesis of color blindness, in the analysis of the results, we also evaluated the number of correct and wrong answers given by the single subjects, to exclude false positives.

For the experiment we selected the images of 5 paintings (see Tab. 1). This decision has been made at first to have a set of images which could be pleasant for the users, but also controlled in terms of gamut mapping. In fact, the selected paintings have been studied to have unsaturated colors thus, to be reproducible without high gamut compression by different devices. Furthermore, the use of paintings allowed us to use in the same test images very similar to the real world (Picture A - Basket of fruit, Picture B – The Tempest and Picture C - The kiss), but also images with unnatural colors (Picture D – Arearea and Picture E – Sunflowers). Thanks to this we had the possibility to evaluate if the effect of gradients and edges on color vision is present independently by the image content, the saturation or the reliability of colors.

In order to test the color discrimination of the users we altered the colors of the paintings simulating different kind of color blindness. The images have been daltonized using two different software Coblis (Colblindor, 2006-2021) and ImageJ (ImageJ, 2021). In Fig. 1 is reported an example of CIExy chromaticity shift of 10 random pixels of Picture E.

Since performing a remote test, it was not possible to assess and verify the type of color blindness of the users, we simulated the three main kinds of color deficiency to daltonize the images, to include all the possible color alterations. Nevertheless this, in this study we do not aim at testing the efficiency of the color-blind simulation but at verifying if a CB person can identify (thanks to gradients and edges) color shifts in chromaticity regions which should be perceived as uniform following the actual CB theories.

In this perceptual test we presented to the subject 4 images, the original, and 3 daltonized versions which simulate deuteranopia, protanopia and tritanopia. In order to assess the contribution of edges and gradients in the color perception we defined three different setups which correspond to three different tests. In the first test, we presented to the subject a paint with a missing piece (see Fig. 2) and the user had to select which piece is the right one, among a set of four daltonized patches (Colblindor, 2006-2021). In this first setup the missing piece must be chosen out of context.
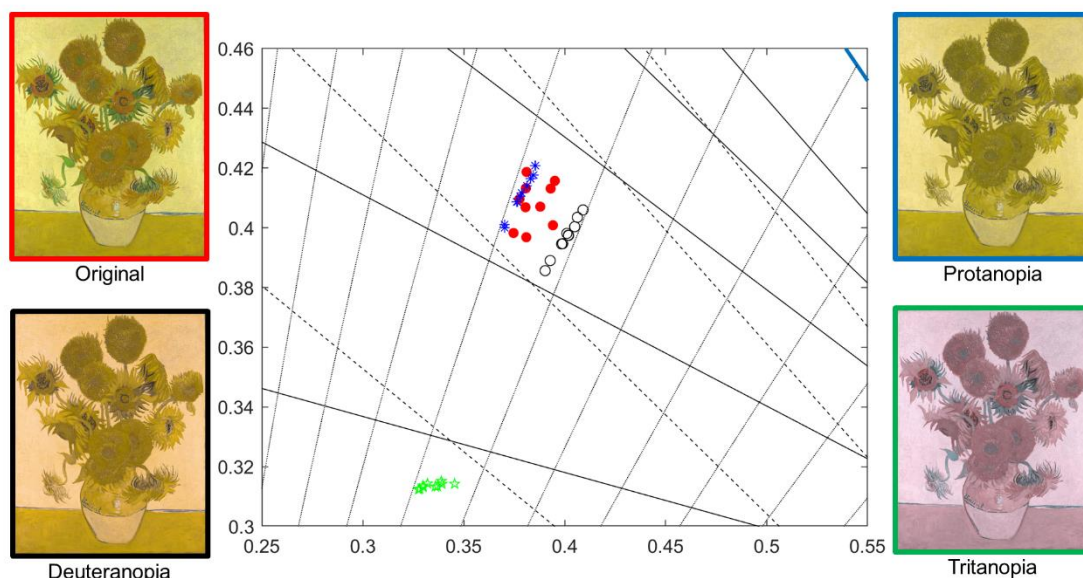

Fig. 1. Example chromaticity shift (CIExy) introduced on Picture E. The filled red dot represents some pixels of the original painting, the black circles the pixels of the deuteranopia simulation, the blue asterisks the protanopia and the green stars the tritanopia. In the chromaticity diagram, are represented also the deuteranopia (solid lines), protanopia (dashed lines) and tritanopia (dotted lines) confusion lines (Judd, 1945).

Picture ID	Description	Artwork
Picture A	Caravaggio, *Basket of fruit*, c. 1596; oil on canvas; 46x64,5 cm. Milan, Pinacoteca Ambrosiana	
Picture B	Giorgione, *The tempest*; 1507-1510; oil on canvas; 82x73 cm. Venice, Gallerie dell'Accademia	
Picture C	Francesco Hayez, *The kiss*; 1859; oil on canvas; 1,10x0,88 m. Milan, Pinacoteca di Brera	
Picture D	Paul Gauguin, *Arearea*; 1892; oil on canvas; 75x94 cm. Paris, Musée d'Orsay	
Picture E	Vincent van Gogh, *Sunflowers*; 1888; oil on canvas; 92,1x73 cm. London, National Gallery	

Tab. 1. Picture ID, description and image of the paintings used in the experiment.

Then, in the second test we presented to the subject four versions of the original painting, completed with the patches presented before (one original and three daltonized) (see Fig. 3) and the subject had to choose which version of the painting is the correct one. In this second setup the missing piece must be chosen inside the image context. This setup has been made to create regular and irregular edges between the overall painting and the patches with altered colors. Thanks to this test we aim at assessing if a wrong-colored image piece placed inside the original paint, is more distinguishable thanks to the presence of edges.

In conclusion, as last test, the subject had to choose again which versions of the painting is the original one, choosing from four version of the painting, one original and three fully daltonized (ImageJ, 2021) (see Fig. 4). In this case, the user had the possibility to compare the paintings under analysis with the previous versions. Thus, in this last setup, we aim at assessing the ability of CB users to identify the overall color of the image, resorting to comparisons.

For all the three tests composing the experiment, we gave to the subject the possibility to select one answer or the option N/D (Non-Defined), when he/she could not perceive any difference among the answers. In the Appendix A are reported all the test images for all the five analyzed paintings.

3. Results

In Fig. 5, 6 and 7 are reported the answers given by the CB and NCB users, divided per painting.

Considering the results of the first test (Fig. 5), the answers are strongly coherent in the first group (NCB) and presents a greater variability in the CB group. For the paintings B, C and D, the majority of the CB answers are exactly like the NCB's, especially in the case of the paint D. For what concerns the paints A and E, just few CB answer correctly, thus there is an increase of variance. For the paintings A and E, 6 people out of 15 answered with N/D.

Also in the second test, the NCB provided quite uniform answers (Fig. 6), but an increase of variance can be observed in the NCB and in the CB answers. Some N/D answers have been reported by the NCB subjects for the paintings D and E, in particular the painting E is the one which presents the majority of N/D answers for both CB and NCB. This painting is the one in which the CB subjects make more mistakes. Considering the CB answers, the visualization of the daltonized patch inside the painting (Test 2) made more difficult the identification of the correct patch, especially for the paint D, where in the first test the CB gave 12 correct answers.

Fig. 2. First test example (picture A).

Fig. 3. Second test example (picture A).

Fig. 4. Third test example (picture A).

Considering, now, the subdivision of the answers per users (Fig. 8 and 9), this analysis could be useful to identify CB people in the NCB group, or vice versa. For what concerns the CB test group (see Fig. 9), 5 subjects out of 15 made more than 4 errors and 11 subjects out of 15 gave N/D answers. A particular trend can be noted for subject 7, who gave the biggest number of wrong answers (13) never choosing the N/D option and for subject 6, who gave 13 correct answers out of 15 (like some NCB people). These results will be discussed in the next Section.
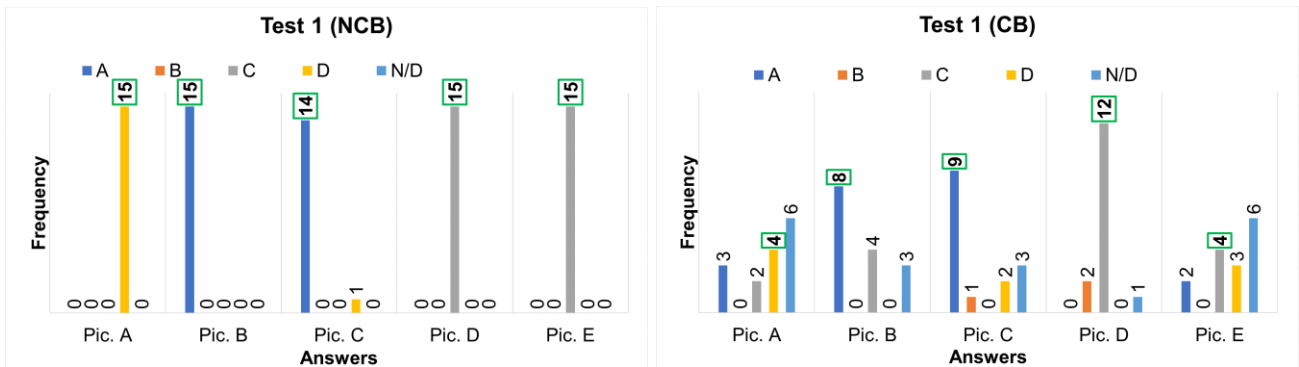
Fig. 5. Comparison of the answers given in Test 1 by NCB and CB subjects. The correct answers are evidenced in green. In these plots it can be noticed that Pic. D is the one which causes less error in CB people, while Pic. A and Pic. E causes the biggest error and variance in the answers.
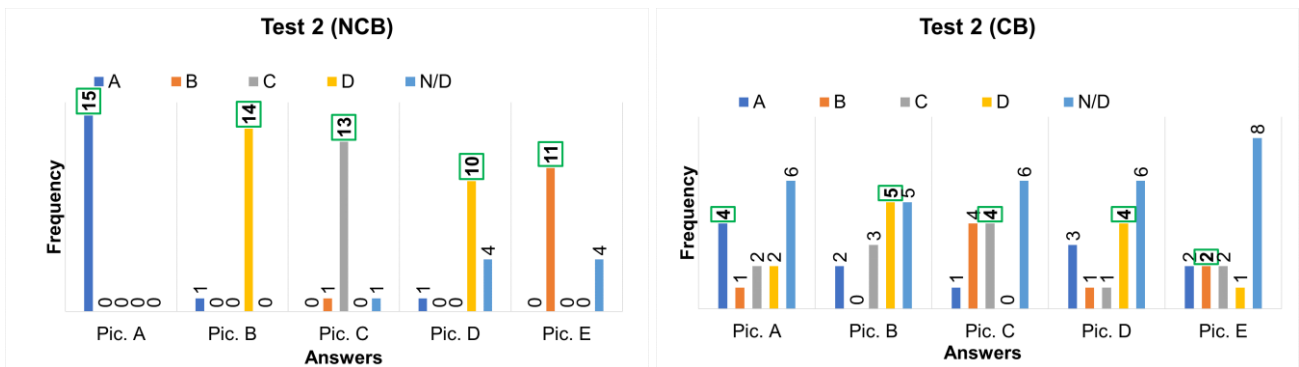

Fig. 6. Comparison of the answers given in test 2 by NCB and CB. The correct answers are evidenced in green. In these plots the Pic. D in NCB presents the lowest value of correct answer. In CB subjects the answer variance is high and Pic. E causes the lowest value of correct answers.
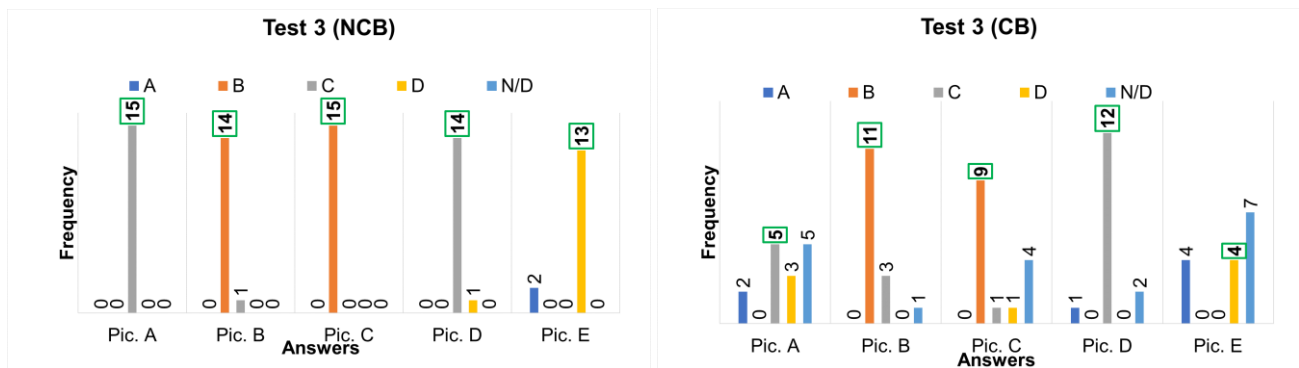
Fig. 7. Comparison of the answers given in test 3 by NCB and CB. The correct answers are evidenced in green. This is the test in which CB people perform better, especially for Pic. B and Pic. D. The images Pic. E and Pic. A produce high error also in this case.

4. Discussion

In general, the NCB test group had no problems in answering to the tests, even if some error (maximum value of 2) is present and some answers are N/D.

In Test 1, the users had to guess the right image missing piece, out of context. In this task, for Picture B, C and D the majority of CB people answered correctly. This result was surprising and unexpected, especially if compared with the results of Test 2. Considering the aim of this work,

this test is very significant because the daltonized patches are reported inside the painting, thus the color differences are seen inside a context with edges and gradients. This test is the one in which the variance in the answers has increased the most and the paintings D and E are the ones which cause more errors in the answers. The answers given by the CB test group are more heterogeneous and, even in this case, the second test created the biggest variance and a greater number of errors. Despite the presence of edges among colors, CB, but also some NCB

people, could not see the difference between the different test images. A preliminary explanation of this result could rely in the assimilation phenomenon of the human visual system. It is clear that this phenomenon must be further studied and analyzed from the physiological, neurological, and psychological point of view, but this result demonstrates the presence of a spatial elaboration of the signal.

This is in line also with the strong decrease of errors in CB test group switching from the second test to third test.

As a consequence, if in NCB people the number of correct answers is robust and constant in the three different tests, for CB people the strong variations could suggest the presence of a spatial elaboration of the signal switching from a situation to another.

Considering now the single paintings (see Appendix A), we can generalize saying that the paints A, B and C

represents subjects which have color arrangements similar to natural scenes, despite the paintings D and E which have non-natural color distribution. This fact could have led to a greater error in NCB and CB test group, especially in the second and third tests, where all the daltonized colors could be considered probable (e.g., in Picture A where an apple is colored in red, green and yellow). On the other hand, considering the setup for Test 1 and Test 3, in an abstract image like Picture D (see Figure 4A in the Appendix), the original painting is clearly distinguishable for NCB as well as for CB people. This happens also for Picture B, which is more similar to a real image, even if in Test 1 the number of error and N/D answers is still high.

Considering the single subject analysis, and in particular the CB test group, the subjects can easily be divided in two groups. On one side we have the subjects who gave more than half wrong or N/D answers (subjects 1, 2, 3, 5, 7, 8
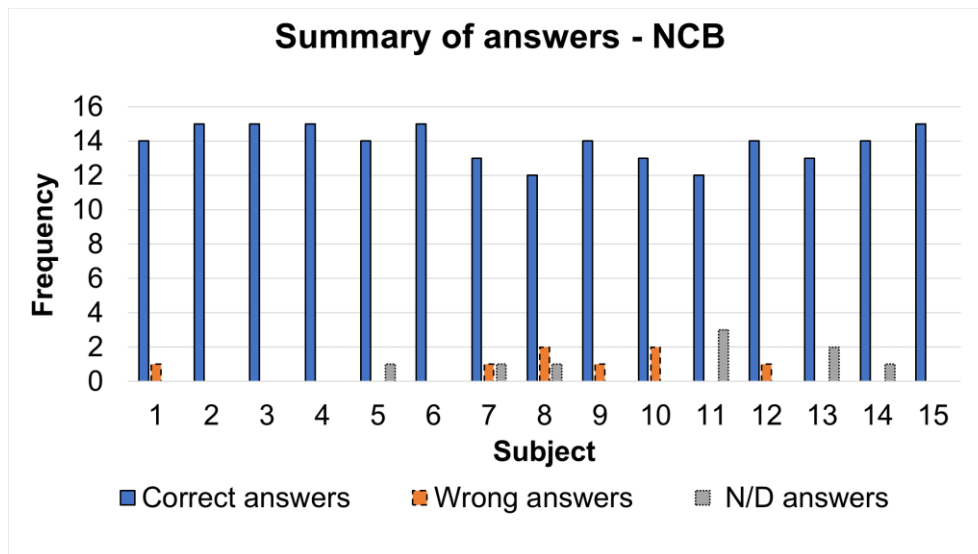

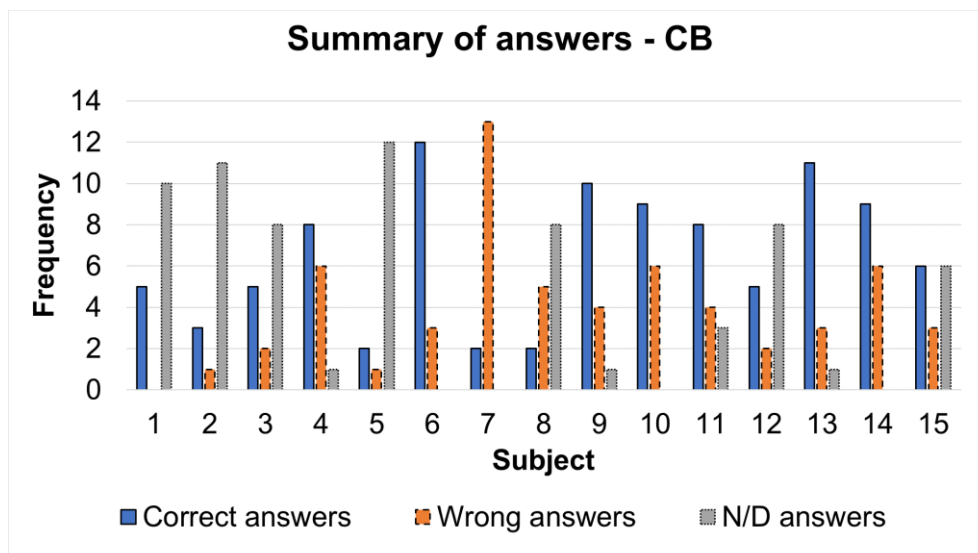Fig. 8. Summary of answers given by the fifteen NCB subjects.

Fig.9. Summary of answers given by the fifteen CB subjects.

and 12) and, on the other side, the subjects who gave more than half correct answers (subjects 4, 6, 9, 10, 11, 13, 14 and 15). From this analysis it is clear that all the CB people, who clearly do not perform as well as the NCB test group, can have not only different types of color vision deficiencies, but also different severity levels. Clearly, also this point should be better analyzed and studied. In addition, as future work, further analysis both in remote and in laboratory conditions should be made, in order to evaluate not only the role of spatial arrangement intended as color distribution in the image, but also the role of different monitor qualities and sizes, and observing conditions in the assessment of color.

5. Conclusion

Color perception is a complex phenomenon which involves not only the signal transduction in the human retina, but also the signal elaboration made by the visual cortex. Color blindness is mainly modeled and studied at the retinal level, since it is an inherited problem which affects the development of one or more type of cone cells. In order to overcome the retinal level in color blindness study and analyze the role of edges and gradients in color vision, we performed three color perception tests. Aim of this study is to assess if the spatial arrangement in which colors are inserted may increase the ability to discriminate colors in CB people.

This was a preliminary study, and further studies and analysis from the physiological, neurological, and psychological point of view are needed, but this experiment has been useful to suggest that the integration of spatial arrangements in models of vision is mandatory, as well as in color blindness diagnosis tests.

This trend has been demonstrated by the test results, but also by the analysis of the single subjects' answers, which show that color deficiency presents different levels of severity. This specific analysis aims to be a further small preliminary step in the direction of rising the awareness of the scientific and medical community on the necessity of developing new methods and techniques able to diagnose not only the presence/absence of color blindness, but also at evaluating and measuring the severity level in real context and not just on isolated patches, not representative of real working tasks

In conclusion, with this preliminary experiment we aim at exploring the boundaries of the actual knowledge about color vision deficiency, evidencing that this phenomenon cannot be studied just at the retinal level but must also consider the visual spatial mechanisms.

9. Short biography of the authors

Sofia Scipioni – She is a student of "Cultural heritage conservation science" at Università degli Studi di Milano. She graduated in "Science and Technology for Studying and Preserving the Cultural Heritage and Information Storage Media" and now her interests and studies are focused on the different way of materials deterioration connected with cultural heritage.

Chiara Andrea Lombardi – She graduated in 2019 in "Science and Technology for Studying and Preserving the Cultural Heritage and Information Storage Media" at the University of Milan with a thesis dealing with the identification of pigments through analytical investigations on Roman wall painting fragments. She is currently obtaining her master's degree course in "Cultural heritage conservation science" at the University of Milan.

Luca Giuliani – He is a master degree student in Computer Science. He obtained his bachelor degree with a thesis concerning a simple implementation of a space variant model for the retinal-cortex vision. Currently he is focusing on distributed systems and IoT devices which could be applied to study human visual perception.

Andrea Mazzoni – Ophthalmologist MD, PhD, Italian Air Force Medical Officer serving at the Aerospace Medicine Institute in Rome. His main task is military and civilian airworthiness. Specialized in clinical and instrumental diagnosis, mostly in anterior segment of the eye. He has been dealing with human visual system perception of colors in a long time. He is currently the head of the research study: "Screening of color blindness in complex operational profiles of military flight: study and analysis of new alternative diagnostic methodologies" collaborating with UNIMI, the University of Milan.

Roberta Marcucci – Ophthalmologist MD, Italian Air Force Medical Officer at Aerospace Medicine Institute in Rome. Her clinical field of application is aviation medicine and the assessment of medical fitness of military and

civilian aviation personnel, according to their special duty status. Her professional background includes medical retina, cornea, refractive surgery.

Alice Plutino – She recently obtained a PhD in Computer Science at Università degli Studi di Milano. Her research interests are: Color Science, Colorimetry, Image Enhancement, Image Digitization and Archiving, with a particular interest in Cultural Heritage applications. She is author of a book on film restoration and of several journal and conference papers of national and international relevance.

Alessandro Rizzi – He is Full Professor at the Department of Computer Science at the University of Milano. He is doing research since 1990 in the field of digital imaging with a particular interest on color, visualization, photography, HDR, VR and on the perceptual issues related to digital imaging, interfaces, and lighting. He is member of several program committees of conferences related to color and digital imaging, and author of about 400 scientific works.

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Appendix A

Fig.1A. First, second and third tests for the picture A (Caravaggio, Basket of fruit).

Fig.2A. First, second and third tests for the picture B (Giorgione, The tempest).
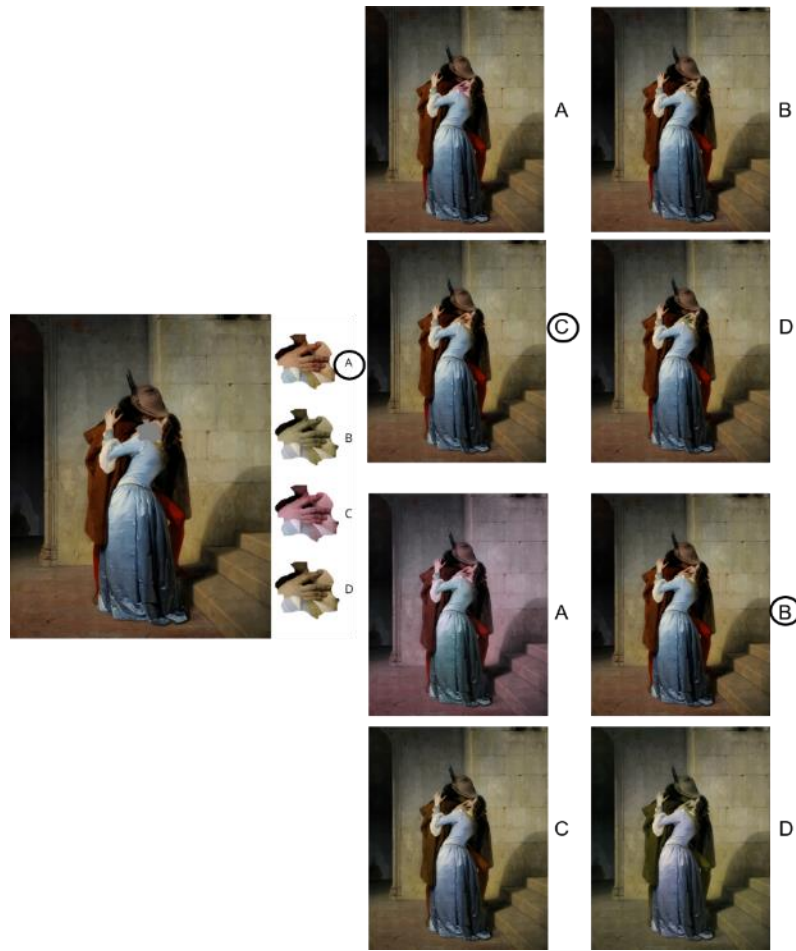
Fig.3A. First, second and third tests for the picture C (Hayez, The kiss).

Fig.4A. First, second and third tests for the picture D (Gauguin, Arearea).
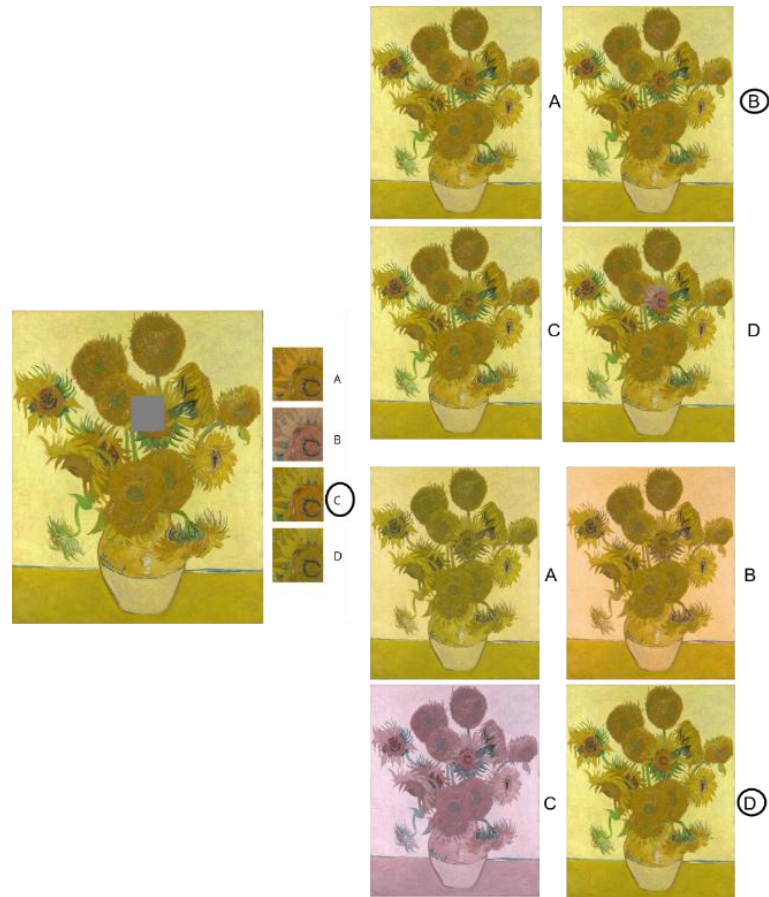
Fig.5A. First, second and third tests for the picture E (Van Gogh, Sunflowers).

Umbrella Diagram: 1981-2021, five decades of forecasts and CMF design

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ABSTRACT

The Umbrella Diagram, developed by Clino Trini Castelli since 1978, is a fundamental tool to configure CMF design languages and forecast historical color and material trends survey. The tool, based on decades, is represented by arches instead of an evolution of a timeline. This cyclical progress proved to be premonitory of the strong changes observed between the color languages of the decades. The umbrella shape of the diagram stems from the coexistence of large arches (historical trends) with smaller arches (fashion trends), frequently in conflict. Castelli first turned to the past of the 70s, 60s and 50s, testing his format backwards based on what was already observed. He then applied the same principles and parameters, looking rather at the 1980s and, till today, to the other four upcoming decades. The Umbrella Diagram was conceived as a proprietary tool of Castelli Design and reserved for his international customers and educational activities.

1. Introduction

This of the AIC 2021 Milan congress is the first public presentation of the Umbrella Diagram executed outside of a professional or educational confidential context. Despite the current presentation of this proprietary tool is taking place exactly forty years after its creation (1980-1981), to this day continue not to be any web recurrences on search engines, except one not-authorized imitations that appeared several years ago using the same graph and the same four basic parameters.

Intending to take over the design company CDM - Consulenti Design Milano, Clino Trini Castelli had already begun, in 1978, the search for a tool that would make it possible to predict the identity of colors and materials languages in advance, as well the related trends.

With the advent of the additive color synthesis era (then completely unnoticed) Castelli founded and directed the Colorterminal IVI in Milan (1978).

The Colorterminal was the first color research center for design and architecture in the world, enabling the chromatic potential discover of the additive RGB synthesis.

The Umbrella Diagram was going to be a new dialogic tool - like the Gretl's Diagram (1977) now in the CCI Collection of Centre Pompidou in Paris - proper for guiding and training also the designers of the first international customers by Castelli Design, including Louis Vuitton.

With CDM, founded in 1974, Castelli introduced the "extensive vision" of the metaproject in the professional field through the Design Primario, this in opposition to the "intensive vision" of traditional design process.

This had led to the development of qualitative aspects of modernity which was still unsolved, as evidenced by the success of the Colordinamo and Decorattivo manuals of the Centro Design Montefibre (1974-1978).
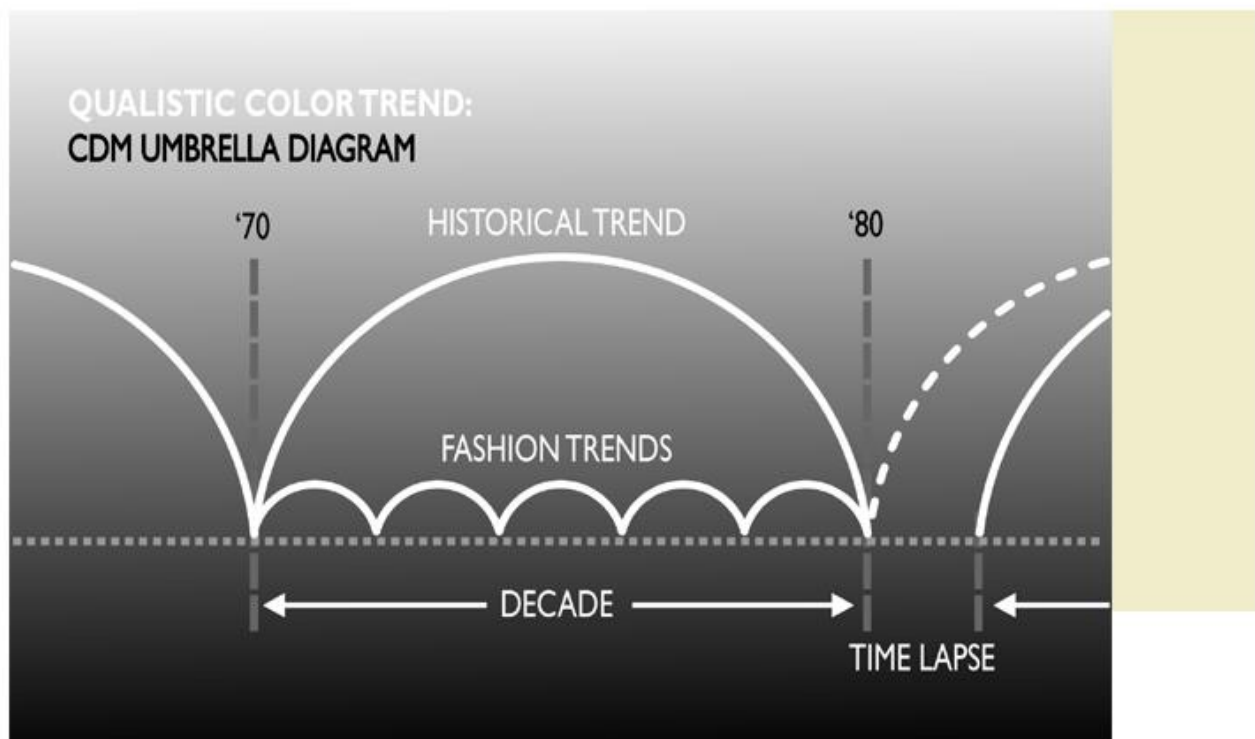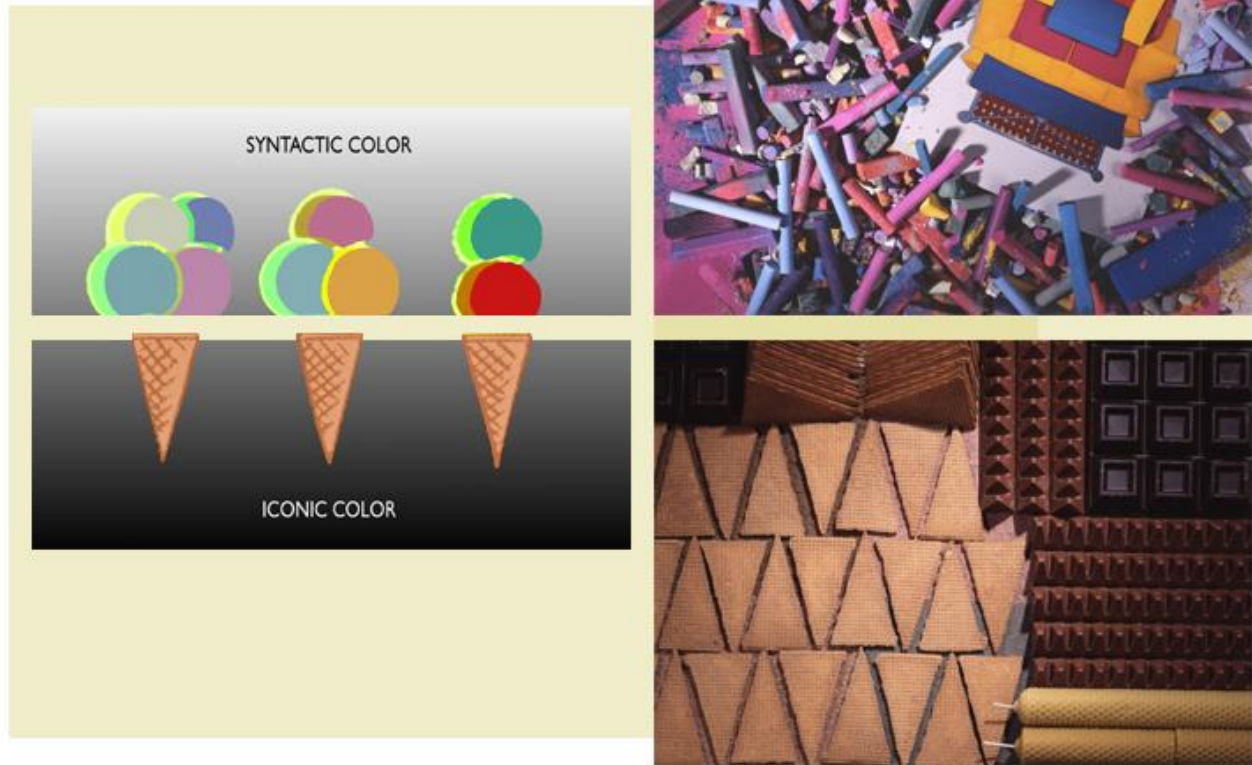

Figure 1. The Umbrella Diagram graph with small and large arches inspired by the Kircher's Diagram (1646).

Figure 2: The Umbrella Diagram Chromatic Nature: Syntactic Color vs Iconic Color.

In the CDM - Consulenti Design Milano, beyond Clino Trini Castelli, Andrea Branzi and Massimo Morozzi, also participated for a while the architects Ettore Sottsass and Alessandro Mendini.

Since 1980 the international activity of Castelli Design - with Vitra in Europe, Herman Miller in the USA and Mitsubishi in Japan - has pointed to a great development of CMF design (Colors, Materials and Finishes), an acronym born in 1981 with the CMF project for Herman Miller by Clino Castelli.

Umbrella Diagram graph:

− Color Arches (Historical Trend arch, Fashion Trend arch).

− Time Lapse (Run-Out or Deviation: anticipation or delay from the ideal Historical Trend).

The Umbrella Diagram graph (Figure 1) is derived from the interlaced arches of Kircher's Diagram (1646) published on the art magazine Data Arte.

The article I diagrammi del colore: Trini Castelli (1978) describes the evolution of the color diagrams found in ancient books and other documents provided to the Colorterminal by Faber Birren, the founder of the Yale University Color Library, with which Castelli had begun to collaborate since 1977.

The Umbrella Diagram is a tool based on decade divisions, represented by large arches instead of the classic linear evolution of a timeline. The main idea was to connect a precise historical color language to a decadic trend, already started from the 50s.

This cyclical progress proved to be premonitory of the strong changes observed between the languages of the various decades.

The umbrella shape of the diagram derives from the coexistence of large arches (historical trend) with smaller arches (fashion trends) that develop, often in conflict with the historical trend of the overlying decade: Raimondo (1982).

When Clino Castelli developed the diagram, starting from 1978, he first turned to the past of the 70s, 60s and 50s, testing the format backwards based on what was already known.

He then applied the same principles, looking instead at the 1980s of the upcoming decades, thus anticipating the great novelty of Post-modern and Memphis polychromatic languages, with their Syntactic and Tonal colors: Lentati (1984).

The qualities that make the Umbrella Diagram tool dialogic and peculiar stand in a specific articulation of the factors of judgment and evaluation of the inherent nature of color (such as: Iconic color / Syntactic color) (Figure 2), on the chromatic characteristics of the colors in use and their application on objects and environments (such as: color Presence / color Distribution) (Figure 3).

These factors are always connected to the social, economic and technological contexts of the individual decades (such as: Socioeconomic context / Technoscientific context).

Umbrella Diagram's original Chromatic Parameters (Table 1) and context:

− Chromatic Nature (Iconic Color, Syntactic Color)

− Chromatic Features (Color Presence, Color Distribution)

− Historical Context (Socioeconomic Context, Technoscientific Context)

2. Umbrella Diagram's Historical Trend Identities

The entire Umbrella Diagram historical trends identities show a sharp decadic opposition jump between the Chromatic Nature languages (Figure 4), that are alternatively Iconic and Syntactic. This is probably due to the need to reach the maximum possible sensation of chromatic novelty.
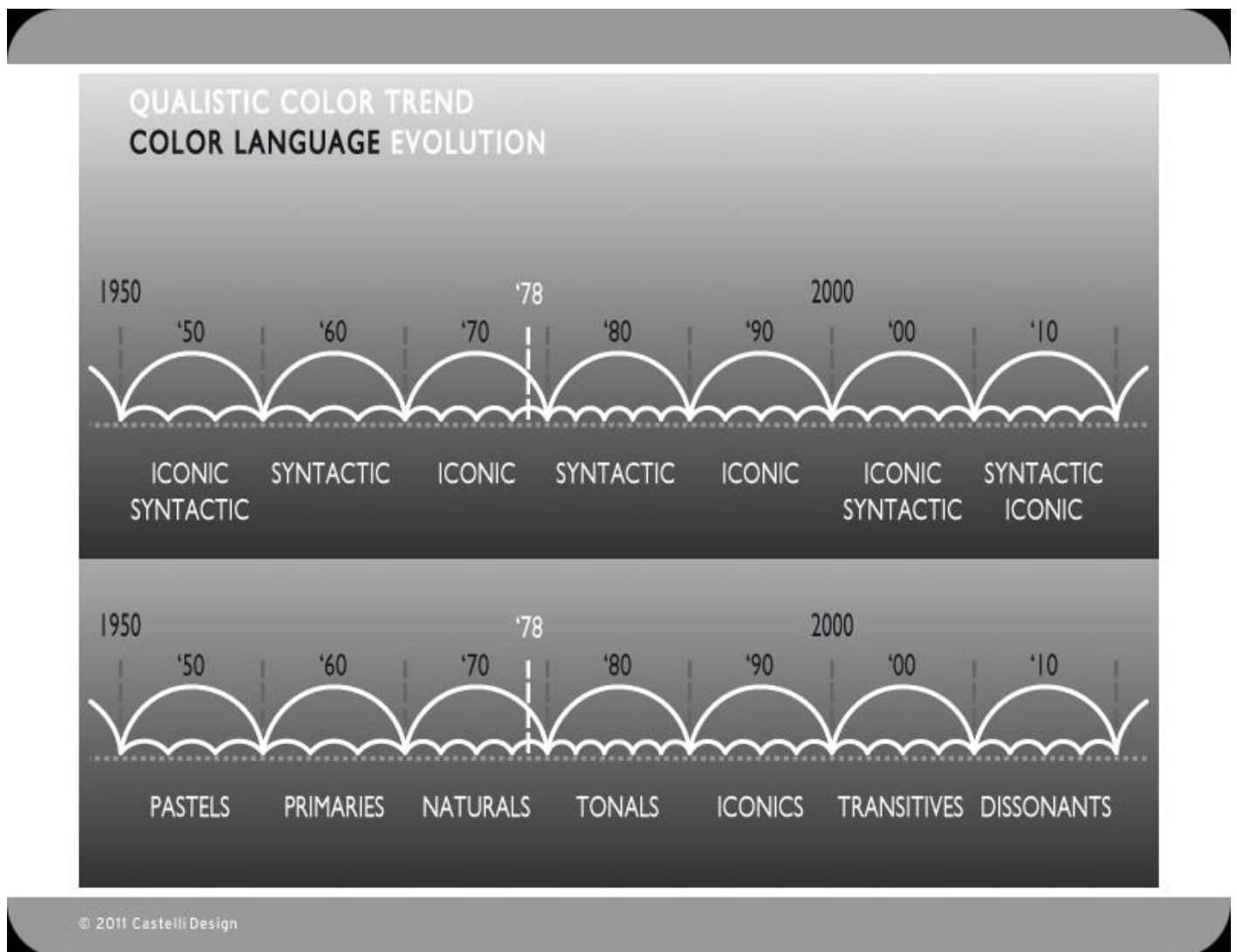

Figure 3: The Umbrella Diagram Color Distribution feature. "The gentleman and the rascal": paradox effect of inverted color distribution on a same black & white color presence.

Decade	Color Presence	Color Distribution	Chromatic Nature
50s	Pastels (Tint)	Bichromatic	Iconic / Syntactic
60s	Primaries	Monochromatic	Syntactic
70s	Naturals	Achromatic	Iconic
80s (Figure 5)	Tonals	Polychromatic	Syntactic
90s (Figure 6)	Iconics	Metachromatic	Iconic
00s	Transitives	Heterochromatic	Iconic / Syntactic
10s	Dissonants	Hyperchromatic	Syntactic / Iconic
20s	Opponents	Autochromatic	Iconic / Syntactic

Table 1: All the parameters seen simultaneously with a hint on 20s decade, that marks the end of the modernity.

Figure 4: The Umbrella Diagram Color Language evolution graph that show the alternation of Chromatic Nature.
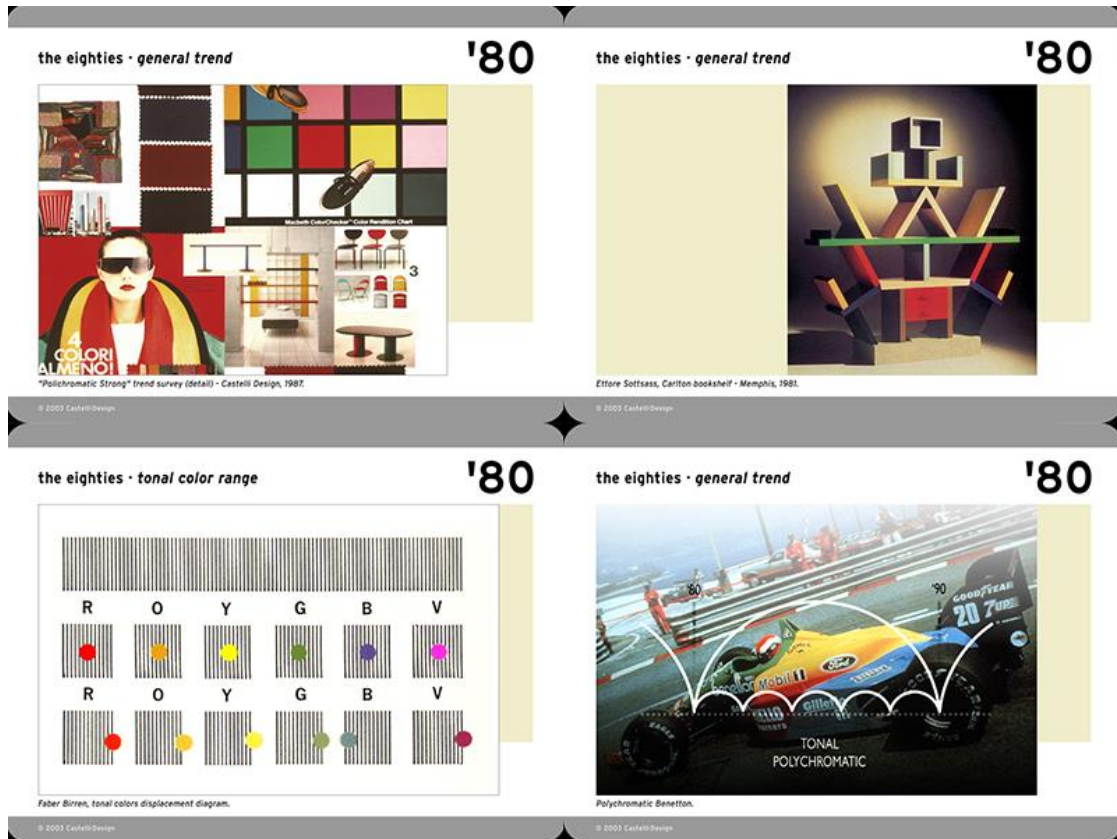
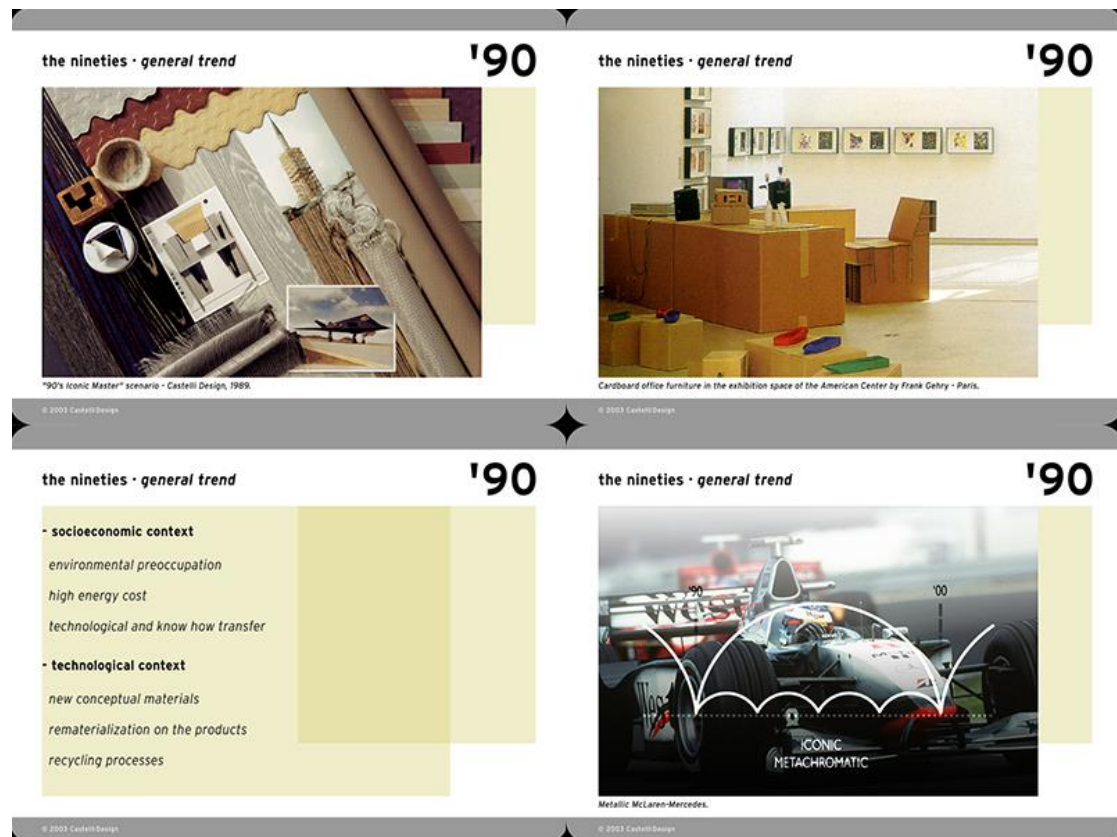Figure 5: The Eighties Color Trend with Tonal and Syntactic languages.

Figure 6: The incoming decade of the Nineties with the Second Ecologism created a strong mutation of the Color Trend in relation to the Eighties.

3. Author's statement on the Umbrella Diagram

"[...] we analyze trends with an umbrella diagram based on decades, which I elaborated at the end of the seventies in order to look back and to look into the future. This diagram is something very important for me [...]": Mitchell (1996: 68).

The diagram format and images were closely linked to the issues that could interest my customers, as the field of new materials (Europe, Japan), automotive production and related CMF languages: Takehara (1984) (Japan, Europe, USA), large office systems (Europe, USA, Japan, Australia), office equipment, including large servers (Europe, Japan), etc. This meant, for example, that for each decade was selected a Formula 1 racing car because, in addition to having a livery suited to the emerging color schemes of the moment, in most cases was also potentially the winning stable.

In addition to the Second Ecologism of the nineties: Trini Castelli (1995), where Color Distribution (Metachromatic) became irrelevant, the Umbrella Diagram has also highlighted the Natural and Achromatic experience of the First Ecologism of the seventies (Club of Rome, 1968-1973) to which I actively participated in its promotion with the magazine Domus.

However, the most sensational anticipation came with the publication of the book Transitive Design: Trini Castelli (1999) and the presentation of the languages of the zero years of the new century where instead the duality of Color Distribution (Heterochromatic) became relevant again. Transitive Design also anticipated the visions of Transmodernity that anticipated the great ecological transition that began after the current global crisis due to the pandemic. This crisis was somehow anticipated by the alarming emergence of the Dissonant harmonies, the extreme languages and Hyperchromatic colors of the 10s.

The Umbrella Diagram has been doubly important to me because over time it has allowed to maintain constant attention to certain signals coming from human ambitions and emotions connected to the global "sentiment of color". This is how I had the certainty of having definitively emerged from what was the long and extraordinary human experience of modernity, to now enter in the 20s of Transitive Times floating season.

4. Conflict of interest declaration

The authors declare that there is no any conflict of interest concerning the content of this article.

6. Short biography of the author

Clino Trini Castelli (b. 1944) designer, artist and design theorist lives and works in Milan. Internationally known for CMF design (Color, Material and Finishes) of which he was the initiator, Castelli introduced the "No-form" renewal of plastic languages applied to industrial products through the tools of Design Primario. As opposed to traditional compositional methods, Clino Trini Castelli has focused on the design of the more intangible aspects of figuration, like color and material, light and sound, emphasizing the virtues of a sensorial approach to art and design. Since the early 1970s this has made him a pioneer in research on the emotional identity of products in the industrial sector. His work has received important European, American and Japanese prizes, including two ADI Compasso d'Oro awards.

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