Colour and Colorimetry Multidisciplinary Contributions

Vol. XIV B

Edited by Veronica Marchiafava and Lia Luzzatto

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1. COLOUR AND MEASUREMENT/ STRUMENTATION

The *Plastique* collection: A set of resin objects for material appearance research

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1. Introduction

We present a collection of resin objects dedicated to the study of material appearance. This collection is both an artwork and a scientific set of objects. The independent artist Aurore Deniel from Aden Keramikk [1] created the collection by commission from NTNU, funded by the MUVApp project (See acknowledgement). She accepted to help us with the analysis through a series of interviews. The artwork is named *Plastique*, which in French, relates to three definitions: the polymeric material, the silhouette of a person, and the class of arts in which the aesthetic is developed around the modification of shape or volume [2, 3]. We shall thus refer to the *Plastique* collection.

In addition to presenting the collection in terms of technical realization, this article contains the interpretation of an interview of the artist. We transcribed the interview on paper and performed an analysis based on the grounded theory analysis [4]. The *grounded theory analysis* is a qualitative research methodology derived from the *grounded theory approach*, which emerged within the Chicago School of Sociology [5]. Through the analysis, we can provide a structured description of the content of this interview and identify the difficulties of realization, but also any processes that may be helpful in the analysis of the future quantitative analysis that will use those samples.

Before going further in the description of this collection, we should recall that our scientific interest is in the visual appearance of materials [6]: this may be defined as total appearance, by the perceptual attributes color, gloss, translucency and texture. Here, we mostly exclude texture as an explicit attribute, but address the three others. The large majority of investigations on visual perception today use virtual reality facilities, from the basic stimulus presentation on a display or stereo-system to complex virtual set-up using VR glasses such as Oculus Rift (see e.g. [7, 8, 9, 10, 11, 12, 13]). Although there are still studies carried out on real materials (e.g. [14]), most of the research is performed through some types of electronic displays. This is for several good reasons. It is indeed difficult technically, and expensive in both time and funding, to realize real samples. The material availability of real samples is reduced, and only available materials can be used, which does not span the whole range of possible physical parameters, which could affect a scaling experiment. The measurement of optical parameters of real samples is very difficult and may be inaccurate, while the computer graphics facilities permit a direct access to the model. Conditions of stimuli presentation are harder to control and visual experiments may be harder or slower to perform. Despite those strong advantages, the computer graphics creation of scenes creates a layer of intermediate media between the light, the object and the observer, so the interaction is less natural. The appearance of an object or material on a display is also very different from a real version of this object,

despite many technological efforts in particular in the computer graphics. In addition, the virtual objects usually do not show any imperfection that may play a role in their visual interpretation.
By realizing these objects, we propose, as future work, to study in depth this corpus and generate a work of theorization about their appearance through different actions. First, we intend to perform optical measurement [15] of each sample type by different means (ellipsometer, gonio-spectrophotometer, camera-based measurements, spectral transmittance and reflectance, etc.), in which we would focus on material definition. This would help to validate procedures of measurement and would be the foundation for further appearance studies. Secondly, we would perform an investigation into the way people interact physically with those samples. Third, we would investigate how people describe the samples. These data should lead to a better understanding of material appearance anchored to this collection and the generation of further research hypothesis.
The purpose of this article is to describe this collection of objects, first from a technical point of view, i.e. quantity of matter, manufacturing processes, that may impact the results of the steps mentioned above. This is developed in Section 2 and 3. Secondly, we would like to convert a part of the artist experience into useful technical knowledge. Because the collection is handcrafted, it is relevant to perform such a qualitative analysis independently. We develop that in Section 4, before we conclude.

2. Description of the objects

This section describes the objects and proposes an adequate labelling system. We wanted to develop a collection of objects that varies in color and in translucency. We identified that the surface of the object, referred to later as coarseness, will influence greatly on both the translucency and the gloss aspect of the object (referred to as *opacity of the surface* by Motoyoshi [16]) as well as the intrinsic material properties. We also understand from the literature that the shape influences greatly the cues generation of material appearance through orientation and thickness (e.g. [8]). Very important features were that there is an achromatic mix from transparent to opaque, but also chromatic components.
In order to have several objects, varying in shape, ratio of mixed components and surface texture, and in a reasonably controlled manner, discussion lead us to resin as material. The price, time and technical difficulties made us limit the number of objects to what is described below. At first, we selected principal hues and primaries but no specific mixes, this decision has been taken later on after some tests, and further discussion, as we wish is described well in the following.
The objects are made of resin *Gédéo* from the brand *Pébéo* [17]. We used the Crystal resin as the Transparent material (T), the Colour resins Lapis Blue (Blue, B) and Topaz (Yellow, Y) version for the chromaticity. The opacity was created by adding drops of white paint (W), *Pébéo ceramic nº 10*, to the crystal resin. The limitation to two hues came from practical reasons. They were chosen as roughly opponent colors. We considered 5 steps of discretization between those 4 primaries (Y, B, W, T) and three level of surface coarseness (C1, C2, C3; C1 being the smoothest surface). See Figures 1, 2, 3, and 4.

The objects are Rectangular, Spherical and Complex shapes. The rectangular shape was selected in order to have a benchmark shape to measure the optical material properties. This shape also varies in thickness, depending on the orientation; cubes have been used in translucency experiments [8]. The spherical shape is selected for isometric properties, and because it will be easy to recreate this shape in a virtual environment for potential comparisons. The complex shape is an original creation by the artist, a meaningful representation, named *Plastique,* and shows different thickness of materials.

Then, a labelling system may be created as Shape-Primaries-Coarseness-Number of the object. An example is S-T1W3B0Y0-C2-N68 for Sphere, Transparent to White level 4, coarseness level 2, object number 68. Ratio of primaries are described in Section 3. All objects are named from R-T4W0B0Y0-C1-N1 to C-T3W0B0Y1-C3-N171 and archived in an Excel file *plastique.xls*.

Figure 1: Image of the spheres from transparent to color to white and the three levels of coarseness.

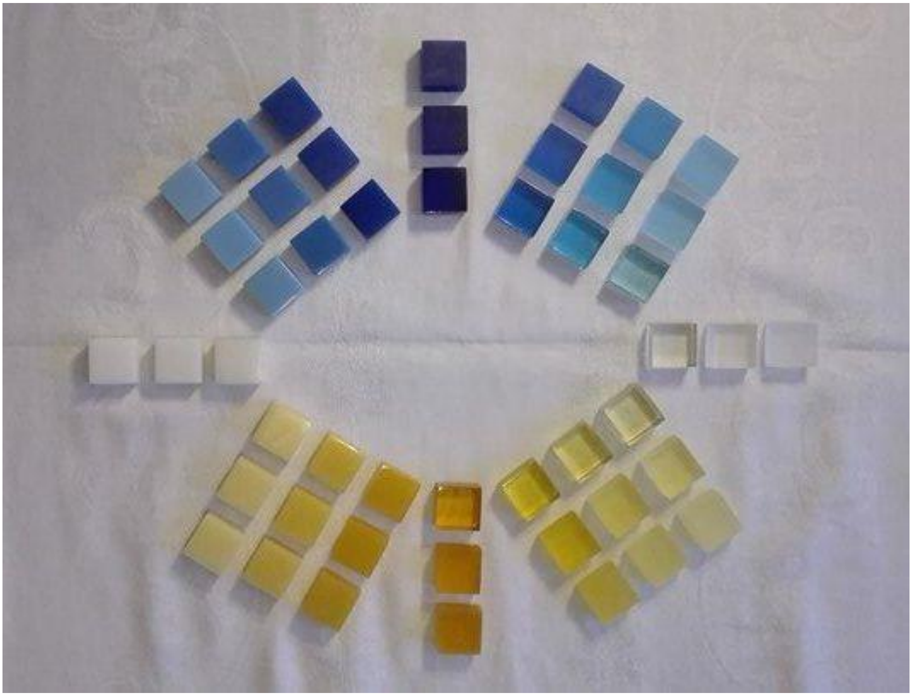

Figure 2: Image of the rectangles from transparent to color to white and the three levels of coarseness.

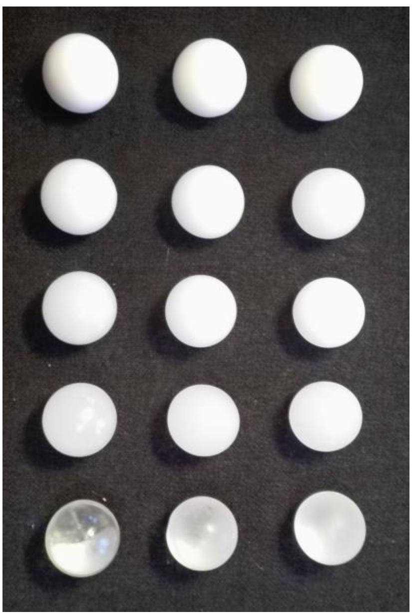

Figure 3: Image of the spheres from transparent to white.

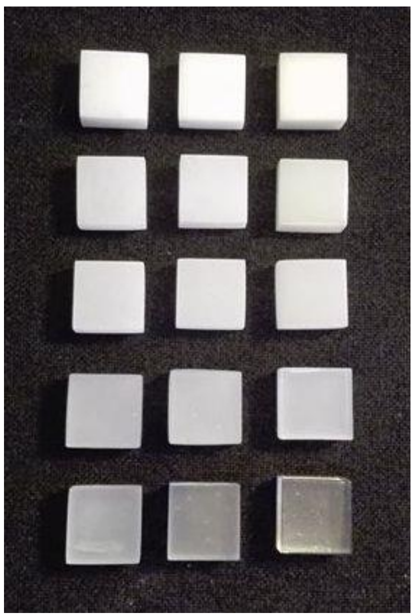

Figure 4: Image of the rectangles from Transparent to white.

3. Description of the manufacturing process

This section describes the manufacturing processes and difficulties of realization.

3.1. Surface coarseness and shape

The rectangle shape has been created with latex flexible molds, with dimensions 27x27x15mm. The mold was opened at one of the square faces. Due to this fact, and to a reduction of volume during the polymerization step, 5 faces were matte but the last face was not planar and very shiny/glossy. It should also be noted that latex is slightly coarse. After molding, each pieces was then reworked by hand.

C1 pieces have been sanded down with a P1200 sand paper (15.3 µm). Then a thin layer of Crystal resin has been applied to regenerate the glossy appearance. C2 pieces have been sanded-down by P120 (125 µm) sand paper, then P1200, then polished with a polishing paste and then by a soft-fabric sander and finally a jean-fabric polishing process. C3 have been sand-down by a P120 paper, followed by a polish-paste and a jean-fabric polishing process. Examples are provided in Figure 5.

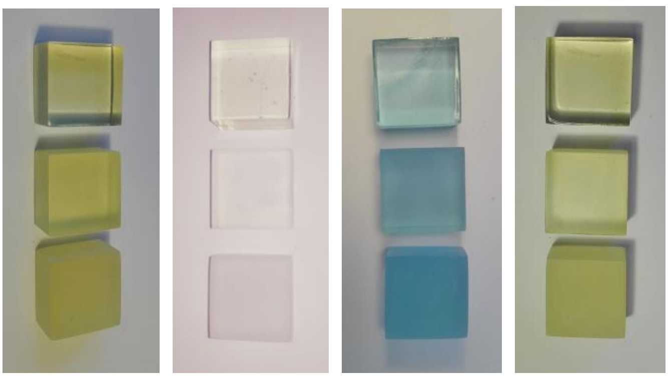

Figure 5: Close up of rectangles with different coarsness.

The sphere shape was achieved with a silicon mold of 40mm diameter, which contrarily to latex produces a very smooth surface. The diameter of the spheres is 40 mm. Essentially, the C1 spheres have not been reworked, except locally where the mold has the filling injection point. Light sand paper and Dremel work has been performed at this point (See next section). C2 spheres have been sand-down with P1200 paper then polished with a polishing paste then by a soft-fabric sander and finally a jean-fabric polishing process. C3 spheres have been sand-down by a P120 paper, followed by a polish-paste and a jean-fabric polishing process. Note that on C2 and C3, the injection point does not appear in the spheres. See Figure 6.

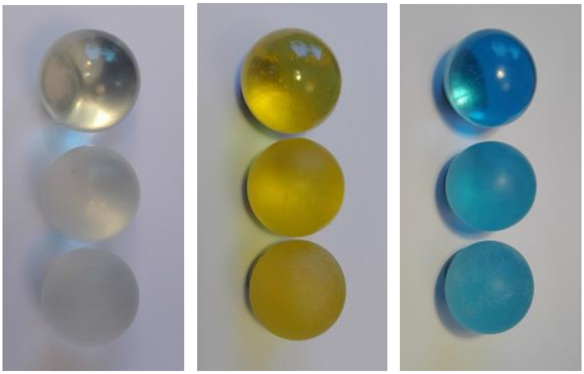

Figure 6: Close-up of spheres of different coarseness.

The complex shape *Plastique* was realized in clay first, then molded with liquid latex by using a paintbrush (many tries were performed before achieving the right mold). The mold was a sock mold, which can be used a single time. Coarseness levels have been generated similarly to the rectangle shape. See Figures 7 and 8. Two objects of the three coarseness levels were generated and served to create silicon molds. The objects were realized from those molds, which permitted to create objects of the adequate coarseness directly for C1 and C2 with the minimum of changes between realizations. Level C3 has been achieved by a similar process than rectangles.

Figure 7: Original clay version of the *Plastique* bust, the *complex object* of the collection.

Figure 8: From left to rigth; Original in clay, broken as per mold creation procedure; one of the liquid latex mold creation; Mold created with liquid latex and reinforced with fabric to avoid deformation; resin object after molding. Three of those objects were created and derived in three coarseness, then served as primaries for the silicon molds.

Figure 9: Image of the resulting collection.

3.2. Selection of resin ratios

In general, for all the different modalities, ratios have been chosen from a visual observation of rectangle shapes of 11 mixtures of two primaries viewed under ambient light. Three ratios were chosen in order to have an approximated perceptually homogeneous step. However, we can observed in the Figures above that this is not obvious on the pictures, and can vary with the illumination, viewing angle and shape. The color mix from transparent to color resins was technically relatively easy: We opted for already-colored resins, so the pigments are already uniformly mixed with an industrial quality. Ratio are in percent as B/T and Y/T: 100/0, 90/10, 80/20, 66.66/33.33, 0/100. This scale has been chosen to be relatively uniform in terms of appearance of color in the mix. The artist mentioned “Colored resins are transparent too, so there is no difference in transparency in those objects.” This is yet to be investigated as pigment presence clearly affect transmission of light.

White opaque resin is created by using 40 drops of white painting (Pebeo Céramic, semi-opaque, Laquée) for 60 mL of the Crystal resin. This painting is showing a lightfastness ***/I of the ASTM D5067 standard (pigments very robust to fading due to light). To create the colored to white objects, ratios are given in percent as B/W and Y/W 100/0, 83.33/16.66, 50/50, 16.66/83.33, 0/100. The gradient is referred to as more or less uniform. The artist stated that along this scale it would have been beneficial to create more samples, because the white resin makes the object opaque very fast, and there is a lot of possible appearance variations along this scale, more than the transparent scale above.

To create the samples from transparent to white, she used Crystal resin and drops of white painting. So that for T/W, the scale is created with 0 drops, 240mL/5d, 180mL/5d, 60mL/10d, 60mL/40d.

3.3. Difficulties of realization

In general, defaults are surface defaults and bubbles present in the resin. Bubbles does not escape from the resin because the injection point may be small and the quantity of matter is large. This is more visible for the sphere due to mold shape. In some of the spheres, some bubbles artifacts appear at the lower half surface.

The injection point of the sphere mold is almost invisible in some spheres, but appearing clearly in others. This area has been manually reworked. An alternative to correct for surface defaults of spheres could have been to attach the sphere to a hook and dip them into Crystal resin. However, this would have the drawbacks of creating a visible artifact in some transparent spheres, which would have served as cue to rate transparency in following experiments, so together with the artist, we decided to stay with more uncontrolled type of artifacts. Surface artifacts also include some brush marks for the coarsest objects.

We imposed some constraints on the complex object, as we wanted an object with complex light interactions and several thicknesses in the object. There were several tentatives and proposals. One of those was fishes in motion, with scales and volutes, which proved to be very difficult to mold with liquid latex, due to many fine details. A Viking warrior bust was proposed, but it was compact and there was not enough variability in material thickness, which is very important in perception of translucency. The choice of the woman body was a good compromise: It is a beautiful object, and it shows several variations of material thickness while still being technically acceptable to model without much variation from one instance to another. Quantities of material to mix, procedure and polymerization time were also part of the difficulties.

We still need to understand how the artist views her artwork. The artist appears to express different feelings about the result. Some dissatisfaction comes from the observation of irregularities in the manual realization of the surface texture and from defaults emphasized by the discovery of a new observation procedure (see next section). However, satisfaction comes for the distribution of colors in both sampling quality, which appears to be regular and beauty of the objects and optical effects generated. The artist mentioned that "This is handcraft; in fact, I could still spend 6 more months to realize better objects."

4. Qualitative analysis of the interview

A series of interviews were conducted with the artist. The 14th of December 2017 was dedicated to the technical description of the object. The 24th and 30th of January and the 06th of February 2018 were dedicated to the description of the basic objects Rectangle and Spheres. We looked at all the collection and observed all pieces independently and in relation with the others. The transcript of these interviews has been separated into two groups. The technical information has been taken out, structured and reported above.

The rest of the transcript of these interviews have been studied according to the *grounded theory analysis*, following the recommendations of [4]. This methodology consists in six steps: Codification (convert transcript into code-words), Categorization (identify conceptual categories from the code-words), Co-linking (understand how the categories interact), Integration (redefine what this system describes, which can be different from what was originally intended), Modeling (reconstruct the dynamic of the phenomenon) and finally, Theorization. The result is a structured description of the content of the interviews. Note that once the categorization step is performed, there is a verification process, which aims at ensuring that the categories exist in the data. Typically, we go back to the transcript and verify that the data can fit into the categories.

The default analysis was still into this corpus, but was finally linked to the technical description, and reported above. Also, the feeling of the artist, that was one of the targets of the research, was dropped as a category and is presented together with the factual description of defaults.

The resulting theorization on the rest of the interviews is presented below, and put in relation two main phenomena: 1-The difficulty of communicating total appearance of materials, and 2-the instability of description depending on observation conditions. This is to be put in relation with the objects, but also to a methodology of evaluation that is created by the observer who is out of resources (An expert in the concept of total appearance had the semantic tools to describe the data very efficiently, but in a less rich way, see below).

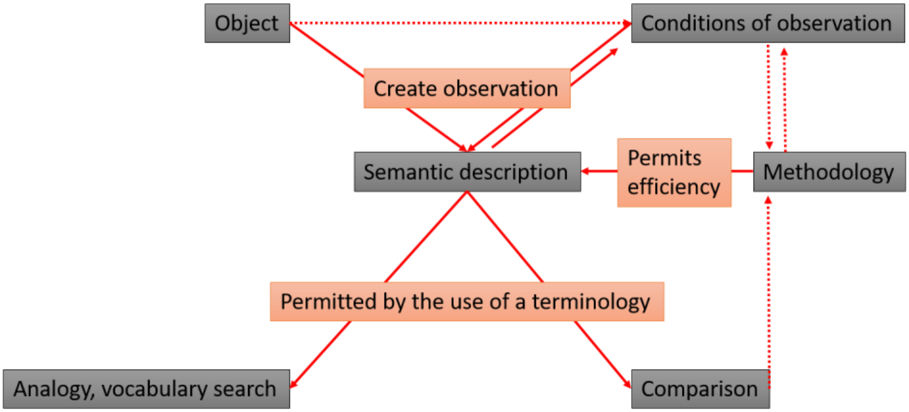

Figure 10: Semantic appearance description process. We observe that the semantic description depends strongly on the conditions of observation and is made stable by the creation of a methodology. The description is based on a vocabulary, that is not always obvious, and strongly based on comparison. We insist on the fact that this is not a model of perception, but a model of the data collected during the interviews.

Figure 10 is the resulting theorization rooted into the interviews content. In gray boxes, the categories that have been extracted from the research methodology, we verified their relevance and their empirical existence by performing the verification procedure. Their interaction is complex, but to us, a way to read this model is as follow: To provide a semantic description of the appearance of the objects, the object is put into a condition of observation according to a methodology, which permits analysis and comparison. The object is described according to these conditions and these methodologies in different ways. One way is the comparison to something else, the other way is to use descriptive vocabulary. The vocabulary is reduced, so there is a searching process involving analogy.

To give sense to this model, we must describe carefully those categories.

The Semantic description itself consists of tentatives to name, to describe. There are also semantic tentatives of general definition more or less successful, e.g. '*Matte: for paints or enamels that do not send back the light and hide suface defects and textures*'. One of the most interesting aspect is that there are many failures in the tentative '*I do not know how/what to say*'. We also observed that analogy was a major description strategy, and that defaults were often used as discriminative hints '*We can see the bubbles in this situation / for this object / for this transparency*'.

The Methodology is a convergence towards a stable, systematic, description process. Until convergence, there is often failure in the description. The convergence aims and permits faster interpretation, continuity in the description and generate a feeling of safety. It is interesting to note that the observer proposed methods for observation naturally, e.g. change light source, specify geometries, etc. but also to note that this convergence happens after a few tries only in both vocabulary and conditions. We also observed several tentatives of generalization, which is quite dangerous and usually only valid very locally in the object collection due to sample diversity.

The Conditions of observation are a predominant cause of instability and are probably the reasons for the need of a methodology. In this category, we include illumination source and optical effects, i.e. description depends on the light source. We include geometry of illumination, viewing angle, which determine strongly what is perceived. We also include the background on which the object is observed (e.g. dark or clear, but also scenes or objects). This situation have a very strong impact on all perceptual attributes!

The Object itself is a key information, yet it is very stable. What seems to influence is the shape, surface, size, but also specific light effect, such as halo projected on the floor for spheres.

Comparison permits to describe objects by reference to something else. We identify similarity and difference to an arbitrary chosen other object. We observe also a comparison based on changes, e.g. between sample N and N-1. There were creation of scales such as '*we see the opposite angle of the object*', '*we see a shape/shadow through the object*', '*we recognize an object that is behind*'. We observe also several instances of what we called a **naïve expression of a physical model**. Example of that is '*In this yellow object, we can see the structure through, but less clear than the blue variant'*, that express a practical understanding of absorption and scattering. We also observe a strong need for reference. Reference could take various form. It could be to see an arbitrary object through the object so description is based on its deformation. Reference could be the light, and how it is deformed within the object. Or it could be that the current is more or less [any adjective/name] than another object of reference, of the same shape or of different shape.

Analogy drove strongly the description due to absence of adequate vocabulary. We observe a need to invent or define a terminology that could be gradual. One observation is that color naming was very important, and include a lot of material related embedded aspects. Vocabulary was fairly rich, with more than 15 color names for objects that have basically two hues (e.g. *aquamarine*). Reference to color atlas also permitted to identify appropriate names, in particular color palette from the make-up industry, that contains a bit more relation to material and appearance than diffuse color atlas. Beside, analogical naming was a basic process, e.g. '*like water*', '*fog*', '*a veil*', etc. Complex appearance terminology was also used, e.g. *Matte, satin, glossy*; *Transparent, translucent, opaque*; *Opalescent and iridescent*.

This is **not** a general model, but only a structured observation of the content of the interviews of one artist performed in French and translated here during the analysis. A very easy example of the impossibility to generalize this model is that an expert in appearance described some objects very fast in terms of translucency, gloss, color and texture (e.g. *no texture, very translucent, blue, quite glossy*). This confirms that we surely do not want to pretend to a generalization of this model. Additionally, the corpus of objects is limited to simple theoretical objects made of a homogeneous material and of no specific use.

Nevertheless, this qualitative description model permits to formulate a few research observation. First, we need to investigate the relationship between observation conditions and constancy, as already identified in the literature, e.g. [10]. Semantic communication of appearance needs also to be studied further, so that the concept of appearance description becomes more familiar and easier to teach, but also that the semantic definition of appearance concepts are aligned with a scientific formulation if possible. The fact that there is a search for reference/comparison is a good hint that we surely can provide a measure eventually. We must put an effort in identifying the adequate references.

5. Conclusion

We introduced a collection of objects, which is intended for research on material appearance. We gathered technical data about the realization of these objects through interview of the artist and co-analysis with her. A model of the interview, which concerns the description of appearance, augments this factual description. Thanks to that, we formulated a few research direction for future research.

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Spectrophotometric evaluation of blue-blocking spectacles lenses

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Abstract

The invention of LED (Light Emitting Diode) has completely changed the world of light sources.

LEDs have replaced the old type of light sources and they are used in the production of screens of all kind of electronic devices such as PC, smart-phones and tablets.

LEDs emit much more short-wavelength light so it's important to fully understand the consequences of this type of radiation on our health.

The discovery of the third retinal receptor have confirmed the importance of blue-light: it controls the circadian cycle which includes all the physiological cycles of our body within 24 hours such as the production of melatonin.

So if we do not get enough blue-light during the day we can accuse sleep disorders.

Lots of studies have shown how an excessive and prolonged exposure can lead to onset of ocular pathologies such as senile macular degeneration or cataract.

More over been exposed to short-wavelength radiation during the evening cause the inhibition of melatonin production which damages the quality of sleep.

For these reasons in the last two years there were introduced many different blue blocking ophthalmic lens. In this study we have measured the spectral transmittance for these lenses. Then

we have defined two indices that could describe the level of protection of the lenses towards the retina (RI, Retinal Index) and the circadian cycle (CI, Circadian Index).

Retinal Index, RI, quantifies the damage that been exposed to the short-wavelength radiation can cause to the retina.

RI is defined as the weighted average of T, spectral transmittance of the lenses, with SD65, emission spectrum of standard illuminant D65, and B, Blue Light Hazard Function which represents the the risk of damaging the retina if exposed to a light radiation.

Circadian Index, CI, quantifies how much the circadian cycle can be inhibited from the exposure to the blue light.

CI is defined as the weighted average of T, spectral transmittance of the lenses, with SD65, emission spectrum of standard illuminant D65, and M, function of spectral efficiency which represents the represents the response of the third retinal receptor to radiation.

The results have shown that there are many different RI and CI. A perfect lens for blue radiation doesn't exist. The right lens should be decided taking into account the environment and the purpose of the lens.

1. Introduction

The invention of the Light Emitting Diode (LED) has completely changed the world of light sources. LEDs have replaced the old type of light sources, and they have been massively adopted in the production of screens of all kind of electronic devices with which many of us deal everyday, such as TVs, PCs, smartphones, and tablets. A particularity of the commonly used white LED is its significant emission of short-wavelength blue light [1]. Thus, it is important to fully understand the consequences of this type of radiation on our health. Recent investigations on the third retinal receptor have shed some light on the importance of blue light for our life cycles. Berson et al. [2] shown that this receptor has a huge impact on the control of the circadian cycle, i.e. the set of all the physiological cycles of our body within 24 hours, such as the regulation of arterial pressure or the production of melatonin. Several studies confirmed that an unnatural exposition to short-wavelength radiation can have a negative impact on our health. For example, an insufficient exposure to blue light during the day has been related to sleep disorders [3, 4], while a strong exposure to blue light during the evening is known to cause the inhibition of melatonin production which damages the quality of sleep [5, 6, 7]. Lots of studies [8, 9, 10, 11, 12, 13, 14, 15, 16] have shown how an excessive and prolonged exposure to this kind of radiation can lead to the onset of ocular pathologies, such as senile macular degeneration or cataract. Optical devices such as ophthalmic, contact, or intra-ocular lenses can be used as a protection from the effects of the blue radiation. Due to the ubiquitous presence of LED devices, we witnessed an increasing interest around those aspects of blue light, with the result of the market introduction over the last few years of many blue-blocking ophthalmic lenses by lens manufacturers. However, there is still a debate in the scientific community and no strict regulations on how short-wavelength visible light should be treated. Thus, it is not clear how lenses should protect us from the negative effects of the blue light (by blocking it) while preserving the positive effects on the circadian cycle. In this work, we propose a novel approach to characterize the interaction of lenses with blue light through the introduction of two numerical indexes. Those are meant to quantify the behavior of lenses when exposed to the blue radiation and to estimate both the risks of retinal damage and disruption of the circadian cycle. We evaluate a set of commercially available lenses with different types of blue-blocking treatments, comparing them with a group of lenses without this type of treatment. Computing our indexes for the analyzed lenses, we were able not only to compare treated and non-treated lenses, but also to capture the heterogeneity of the behaviors of the different blue-blocking lenses. The paper is structured as follows. In section 2, we briefly introduce the numerical parameters used for the analysis of the lenses, giving the definition of the two novel indexes we propose in this work. In section 3 we report the experimental settings, in section 4 we expose and discuss the results of this study, and section 5 concludes the paper.

2. Characterization of the interaction of lenses with blue-light radiation

In this section, we describe the two proposed indexes to characterize the response of lenses to the exposure to blue light, respectively named *Retinal Index* (RI) and *Circadian Index* (CI).

Retinal Index (RI) The Retinal Index (RI) quantifies the possible damage of the retina due to the exposure to the short-wavelength radiation. We define RI as

$$RI = \frac{\int_{380nm}^{780nm} T(\lambda)I(\lambda)B(\lambda)d\lambda}{\int_{380nm}^{780nm} I(\lambda)B(\lambda)d\lambda}$$

where T(λ) is spectral transmittance of a lens in the visible spectrum (380 – 780 nm), defined as the ratio between the transmitted flux and the incident flux [17], I(λ) is a generic illuminant, and B(λ) is the blue light hazard function (depicted in Fig. 1). B(λ) represents the risk of damaging the retina if exposed to a blue-light radiation [18]. RI ranges from 0 to 1, where a RI = 0 identifies a totally protective lens against the photochemical retinal damage due to blue light, while RI = 1 identifies a totally non-protective lens.

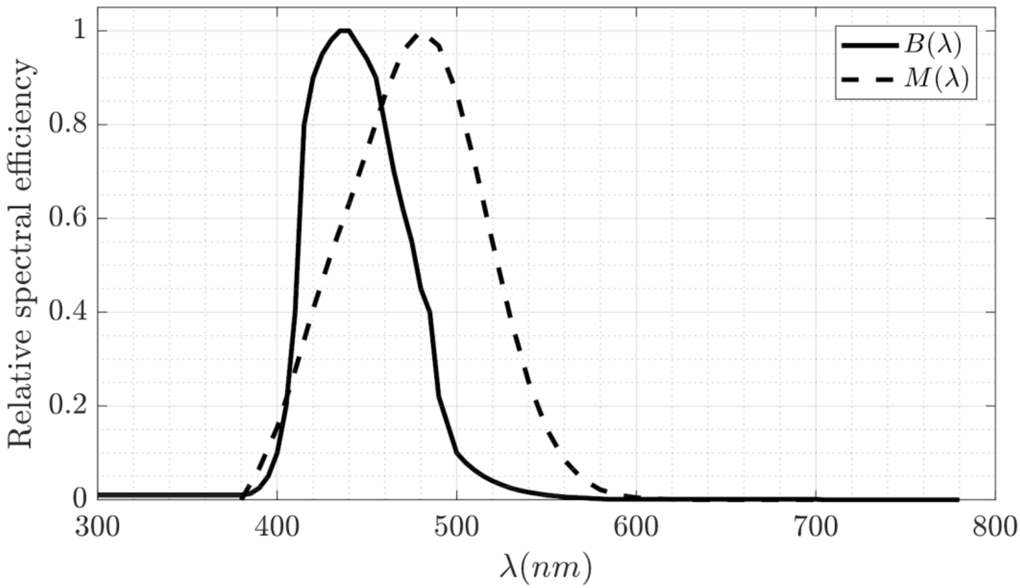

Figure 1: Comparison between B(λ), Blue Light Hazard Function, and M_λ, a relative spectral efficiency function which represents the represents the response of the third retinal receptor to radiation.

Circadian Index (CI) The Circadian Index (CI) quantifies the ability of a lens to inhibit the effect of the light radiation in the circadian cycle. We define CI as the weighted average of the spectral transmittance of the lens.

$$CI = \frac{\int_{380nm}^{780nm} T(\lambda)I(\lambda)M_\lambda d\lambda}{\int_{380nm}^{780nm} I(\lambda)M_\lambda d\lambda}$$

where T(λ) is the spectral transmittance, I(λ) is the emission spectrum a generic illuminant, and M_λ (depicted in Fig. 1) is a relative spectral efficiency function that represents the response of the third retinal receptor to the light radiation [19, 20]. The function M_λ takes into account how much the circadian cycle is influenced by the received radiation. CI ranges from 0 to 1, where a CI = 0 identifies a lens that completely blocks the effects of the blue light radiation on the circadian cycle, and CI = 1 identifies a lens that does not interfere with those effects. When using a lens with CI = 1, the natural circadian cycle could be altered by the exposure to the artificial blue light of digital devices, but the same lens allows the natural rhythm of the circadian cycle in the case of natural, solar light exposure. On the other hand, a lens with CI = 0 protects from the damages caused by the artificial blue light, but, at the same time, does not allow the natural blue light to reach the third retinal receptor.

UV Transmission Factor (τ_{UV}) To fully characterize the quality of a lens, we also measure and report the Solar UV transmission factor, τ_{UV} , defined as

$$\tau_{UV} = \frac{\int_{280nm}^{380nm} T(\lambda) W_\lambda(\lambda) d\lambda}{\int_{280nm}^{380nm} W_\lambda(\lambda) d\lambda}$$

where T(λ) is the spectral transmittance of a lens, and Wλ(λ) is the weighting function for UV transmission as defined in (European Regulation UNI EN 1836). This index takes into consideration the percentage of ultraviolet radiation that a medium is able to transmit.

3. Experimental Settings

For this study, we analyzed 16 commercially available blue-blocking lenses from 8 different companies and 5 lenses without any blue-blocking treatment. The characteristics of the analyzed lenses are reported in Table 1. We measured the spectral transmittance T(λ) using the spectrophotometer Perkin Elmer Lambda 1050 UV/Vis/NIR double-bean with integrating sphere. Since we were interested in the behavior of the lenses in the visible and UV spectra, we measured T(λ) for 280 nm ≤ λ ≤ 830 nm, with a stride of 5 nm, in order to obtain a good compromise between measuring times and preciseness, as suggested by the main ISO regulations. For each lens, we computed RI, CI, and τ_{UV} using two different illuminants I(λ), the standard illuminant D65 (RI_{D65} e CI_{D65}), and the spectral emission of a LCD screen, in particular the one of an iPad (RI_{LCD} e CI_{LCD}). By changing the illuminant it's possible to study the behavior of a medium when exposed to different type of radiation. The MATLAB code for the computation of the indexes is publicly available .

4. Results and discussion

The computed indexes for all the lenses and both the illuminants are reported in Table 1. Figure 2 shows the scatter plot of RI and CI of various lenses computed using the spectral emission of the standard illuminant D65. Although it is clear that blue-blocking lenses are on average more protective towards the effects of blue light with respect to non-treated ones, we notice a heterogeneity in the RI and CI values among treated lenses that is not reported by lens manufacturers. For example, lenses with a different CI should be used for different needs, e.g. lower CI lenses might be used with electronic devices in the evening to prevent sleep disorders, while they are not recommended in the daylight in order to preserve the natural circadian cycle. Instead, lens manufacturers generally advertise lenses with blue-blocking treatments as globally protective against blue light without distinguish those aspects.

Table 1: List of all the analyzed lenses. When available, we also report their refractive indexes ($\boldsymbol{n}$), whether they had a blue blocking treatment (**BB**), and the RI and CI computed with the standard illuminant D65 ($\boldsymbol{RI_{D65}}$, $\boldsymbol{CI_{D65}}$) and the spectral emission of a LCD screen ($\boldsymbol{RI_{LCD}}$, $\boldsymbol{CI_{LCD}}$).

Lens	n	BB	RI_{D65}	CI_{D65}	RI_{LCD}	CI_{LCD}	$\tau_{UV}\%$
1	1.50	y	0.77	0.84	0.78	0.84	3.1
2	1.50	y	0.86	0.92	0.92	0.93	3.3
3	-	y	0.86	0.92	0.88	0.92	1.7
4	-	y	0.90	0.93	0.90	0.93	4.9
5	-	y*	0.10	0.23	0.09	0.24	0.0
6	1.50	n	0.84	0.85	0.85	0.85	4.8
7	1.59	y	0.79	0.86	0.81	0.87	0.0
8	1.74	y	0.79	0.87	0.85	0.89	0.0
9	1.60	y	0.74	0.82	0.77	0.83	0.0
10	1.67	y	0.78	0.86	0.83	0.88	0.0
11	1.59	y	0.85	0.91	0.92	0.93	0.0
12	1.60	y	0.83	0.89	0.91	0.93	0.0
13	1.67	y	0.82	0.89	0.91	0.92	0.0
14	1.50	y	0.84	0.90	0.90	0.93	0.0
15	1.50	y	0.75	0.87	0.92	0.93	0.0
16	1.60	y	0.80	0.90	0.96	0.96	0.0
17	1.60	y	0.82	0.91	0.97	0.97	0.0
18	-	n	0.97	0.97	0.98	0.98	5.2
19	1.50	n	0.88	0.90	0.89	0.90	2.8
20	1.50	n	0.87	0.89	0.88	0.89	2.8
21	1.50	n	0.92	0.92	0.92	0.92	66.7 †

* Lens 5 is an orange-tinted lens.

† Lens 21 is a non-organic glass lens without any treatment.

Indexes Correlation We can observe that there is a positive correlation between the two indexes. This is reasonable since the peak values of B(λ) and M_λ (on which the definition of RI and CI are based) are near in the spectrum, and there is a significant overlap of the areas under the two curves (see Fig. 1). This means that the two aspects of the blue light, i.e. the effect on the circadian cycle and the damages of the retina, are difficult to separate. In Figure 3, the two curves B(λ) and M_λ are shown together with the spectral transmittance of two chosen lenses (Lens 1 and 2). These lenses are two samples of the same material and made by the same company, but with two different blue-blocking treatments, which we refer to as Treatment A and Treatment B. We can observe that the spectral transmittance of the lens with Treatment B reaches a high value near the higher point of curve (450 nm ≤ λ ≤ 500nm); thus, it has a higher

CI_{D65} than the lens with Treatment A. On the other hand, a side effect of Treatment B is that the spectral transmittance near the peak of B(λ) curve (400 nm ≤ λ ≤ 450nm) is equally high, yielding a higher RI_{D65} with respect to Treatment A. However, we can notice that there is a clear depression in the spectral transmittance under the B(λ) curve right before its peak, which prevents the retinal index to further increase.

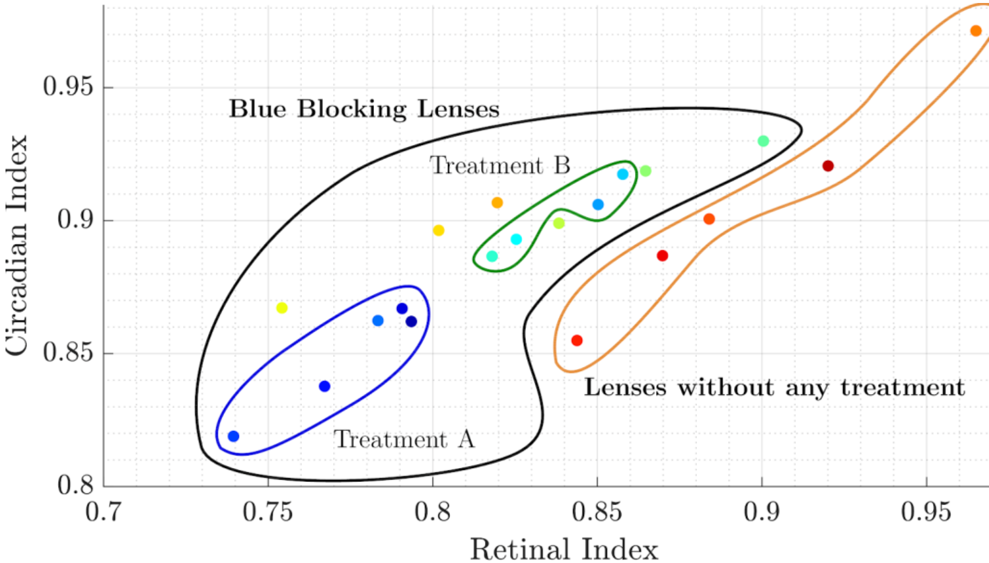

Figure 2: Scatter plot of RI and CI some of the evaluated lenses. The reported indexes are calculated using the standard illuminant D65.

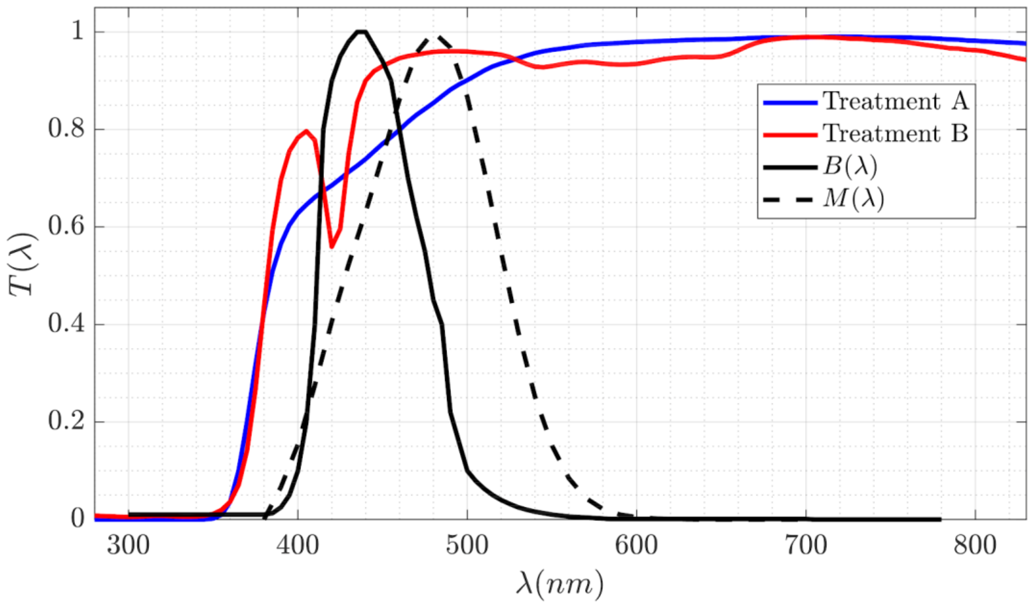

Figure 3: Comparison between B(λ), M_λ, and the spectral transmittance T(λ) of two blue-blocking lenses (Lens 1 and 2) of the same material with different treatment (Treatment A and Treatment B highlighted in Figure 2).

Relation to UV transmittance In Figure 4, the spectral transmittances of all the analyzed lenses with blue blocking treatment are shown, with particular attention to the cut-off wavelength. We notice that four lenses (Lens 1 to 4) have a lower cut-off wavelength and thus present a higher UV transmission factor τ_{UV}. Despite being advertised as a protective lens with blue-blocking treatment, Lens 4 have the highest values of RI_{D65}, CI_{D65}, and τ_{UV} among all lenses with blueblocking treatment; thus it offers a very limited protection against the effects of the exposure to blue light. Moreover, it is the less protective less against UV radiation among all the treated ones, with a τ_{UV} value comparable to the ones of non-treated lenses. Lens 1, which is the one with the Treatment A, has a lower value of RI_{D65} and CI_{D65}, but still has a high value of τ_{UV}, which is comparable to the one of lenses without blue blocking treatment. It is important to notice that the values of RI and CI are independent from τ_{UV}; thus the proposed indexes are not meant to describe in any way the behavior of the sample to the ultraviolet radiation.

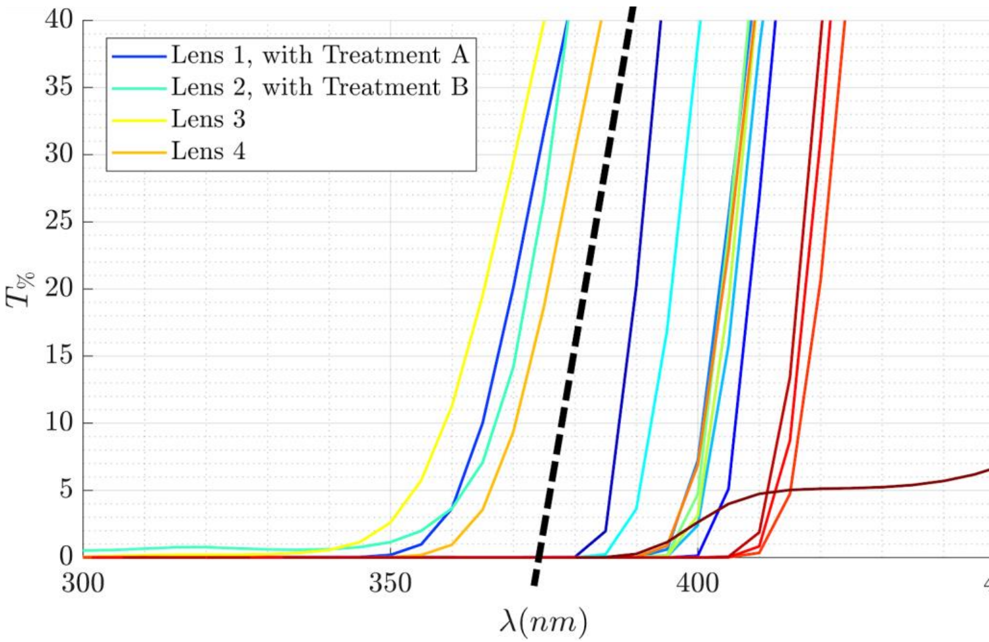

Figure 4: The detail of the spectral transmittance of all blue-blocking lenses around the cut-off wavelength λcut.

Chromaticity of Lenses In Figure 5, we highlight the chromatic coordinates of three lenses of interest in the CIE color space chromaticity diagram. The curve in the center of the diagram delimits the set of chromatic coordinates for which the color perception is not altered [21]. We observed that lenses with blue-blocking treatments do not lead to an altered color perception; in fact, all blue-blocking lenses fall inside the delimited area. Lens 1, treated with Treatment A, is the most yellow lens out of all the one in the acceptance area; still, it is very near in the chromaticity space to Lens 6, a non-treated lens which is the most white of all the analyzed lenses. The only lens that lies outside the acceptance area is Lens 5. Since it is an orange-tinted lens, we expected it to alter the perception of color. This accounts also for the low values of RI_{D65} and CI_{D65}, since the strong orange tint blocks the majority of the blue radiation. All the other lenses had color coordinates that lie approximately between the coordinates of Lens 1 and Lens 6.

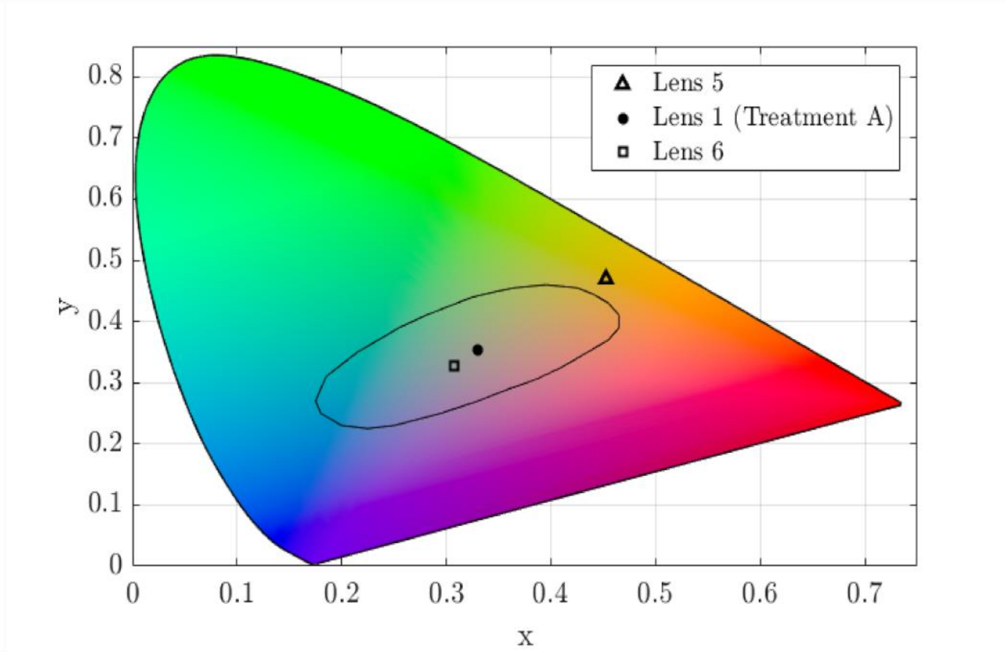

Figure 5: The CIE color space chromaticity diagram. The points represented three out of all the analyzed lenses (with and without blue blocking treatment).

5. Conclusions

In this work, we proposed two numerical indexes, namely the Circadian Index and the Retinal Index, to quantify the effects of the exposure to short-wavelength visible radiation to the human health. Given a lens, the former summarizes impact of the transmitted light on the circadian cycle, while the latter summarizes the risk of retinal damage when exposed to same transmitted radiation. Using these indexes, we performed a comparative analysis between commercially available lenses with blue-blocking treatment and non-treated lenses. Results shown there is a large dispersion of behaviors among different treatments. Our proposed indexes are able to efficiently capture those differences, and they could be useful as a metric to characterize blue-blocking optical media. Differently from already proposed index measuring global blue light transmission, we argue that having two separated metrics could help to easily identify the optimal lens for a particular usage. While it is always desirable to have a lens protecting from retinal damage, i.e. with a low RI, we may want to choose whether to block the effects of blue light to the circadian circle (with a low CI) or not to (with a high CI), depending on the needs of the user. In order to encourage further research in this field, we released the data and MATLAB code to compute the proposed indexes and to replicate the experimental results.

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New evidences on colour quantity contrast in Itten's theory

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1. Introduction

The present work represents a sequel of previous studies published in the Proceeding of *Conferenza del Colore* and in the Colour Culture and Science Journal [1-2] and it is aimed to verify the statement regarding the relationships of quantity of the six primary and secondary colours of subtractive synthesis of Itten [3]. For easy reading this paper, we reported the values of the reciprocal relationships of colour brightness, according to Itten [3]. They, as said in the previous articles, would have been the following:

yellow	:	orange	:	red	:	violet	:	blue	:	green
9	:	8	:	6	:	3	:	4	:	6

According to Itten, "*To translate the brightness values in harmonious values of quantity, the numeric ratio has to be inverted: so, the yellow, for example, being three times brighter, should be have a surface three times smaller than complementary violet colour*" [3]. In this perspective, the quantity relationships available for complementary colours are the following:

yellow : violet	=	1/4 : 3/4
orange : blue	=	1/3 : 2/3
red : green	=	1/2 :1/2

and so the harmonious proportions of the primary and secondary colours are:

Yellow	:	orange	:	red	:	violet	:	blue	:	green
3	:	4	:	6	:	9	:	8	:	6

Furthermore, in the published studies we discussed about the authorship of the statement reported in "The art of Colour" [3] and we concluded that this statement is not attributable to Goethe but to Schopenhauer. In addition to that was already stated in the past articles [1-2], some additional considerations are taken from the Josef Albers book [4] in which he not only attributed to Schopenhauer the paternity of the statement but even gave rise precisely to this aspect the motif of the great disagreement between Schopenhauer and Goethe. "*It was above all Schopenhauer who recognized this property. Going to improve Goethe's six-colour circle-with consternation of Goethe- Schopenhauer changed the previous presentation by replacing the six equal areas with others of decidedly different quantities*." From this simple statement, Albers simultaneously clarifies two aspects that in Itten were neither exposed nor emphasized. He explicitly attributes the paternity of the statement to Schopenhauer and at the same time defines exactly the reason for the disagreement between them, very well evident throughout their epistolary entertained for several years. In this regard, one wonders how such a different attribution of the paternity of the statement was made by Itten and by Albers given that, both Itten and Albers, for

over a year were teachers of the same subject course of basic painting at the Bauhaus of Gropius and Albers himself succeeded to Itten in 1925.
The published studies were based on colour specification measurements on samples ad hoc prepared in two different laboratories. In particular, in order to check the effectiveness of the thesis, two different categories of samples of six primary (yellow, magenta, cyan) and secondary (orange, violet and green) hues of subtractive synthesis were prepared. Liquitex Ink, LeFranc&Burgeois Flasche and Maimeri acrylic and Van Dyck Ferrario and Maimeri oil industrial products belong to the first category. They were painted on a hardbound support Acrylic Pad Galeria of Winsor &Newton 300 g/m^2. Each colour was painted with three coats with a brush of natural bristle directly on hardbound support without any preparation. The study had confirmed as expected in terms of the qualitative trend of values of reciprocal relationships of the six colours. On the other hand, it has putted in evidence a quantitative difference, respect to the six colours theorized by Itten, in the quantity contrast.
The importance of the results obtained in the precedent research studies and also the foreseeable fallouts in several fields let us to explore more deeply by increasing the number of colours and supports samples, improving the preparation steps and optimizing and standardising the colour coating method in order to achieve a quality surface and homogeneity better than the one obtained. As putted in evidence in our previous studies [1-2] the characteristics of a coloured coating depend from a wide range of variables that are taken into account in this research work. New samples, on different supports, with a very good homogeneity and high quality, with different type of inks and colours, mixed or overlapped, painted by hand using brushes or drawdown bar or roto/flexo/inkjet printing were obtained. In total, we presented the results related to 153 samples were obtained. On these samples, in detail described in the paragraph 2.1, the colour specification is carried out through spectrophotometric analysis that simulates the visual perception of the human eye (*actio retinae*). The experimental protocol [5] used to perform the analysis was illustrated in the paragraph 2.2. Further, in the paragraph 3 we will present results obtained and we will discuss about them. Finally, in paragraph 4 we will report the conclusions.

2. Materials and Methods

2.1 The samples

In order to achieve the objective of the study and the effectiveness of our thesis, a wide set of materials has been prepared. In general, we focused on two categories of samples: the primary and the secondary hues of subtractive synthesis. Respectively: Cyan (C), Magenta (M), Yellow (Y), Orange (O), Violet (V) and Green (G). The secondary hues were obtained in two ways, mixing at 50% in weight or overlapping dry on dry with different methods the primary ones.
The samples were prepared with two type of inks, water or solvent (ethyl acetate) based. The inks were applied on different supports: paper with 80 gr/mq and 120 gr/mq; PolyEthylene Terephthalate (PET) and Oriented PolyPropylene (OPP). About the coating preparation, we adopted essentially three methods. A group of samples was realized by hand with brushes, by drawdown bar and the majority through roto/flexo/inkjet printers machines.

In order to organize materials, means and methods employed, we divided the samples into two sets. The preparation methods for obtaining the first one are described in Table I.

Table I – The eight preparation methods used for first set of samples prepared.

Method	**Number of samples**	**Ink**		**Support**				**Coating**			**Secondary hue**	
		Water based	Solvent based	Paper 80gr/mq	Paper 120 gr/mq	PET	OPP	Brush	Draw down bar	Printing	Mixing	Overlapping
A	18		X		X			X			X	
B	18		X		X			X				X
C	6		X				X		X		X	
D	18		X		X					X		X
E	30		X	X						X		X
F	6	X				X				X		X
G	6		X				X			X		X
H	6		X				X			X		X

For this first set with 108 samples, all methods except C, F, G and H have inside them subgroups regarding the preparation coating. For each sample, in fact, we have to consider different steps (from 1 to 5) in printer. This was necessary in order to made considerations also about the optical density. In the following text, the samples of the indicated method present the subscript that indicates the number of steps with which they are obtained. The Figure 1 is useful to explain what we just said. Showing as example the samples of D method, the image sums up the coating preparation. In particular, the section A-A presents colours with minimum hue due to minimum amount of ink obtained with just one passage of paper in inkjet printer. In section B-B, we can see results with maximum hue with five layers for each colour.

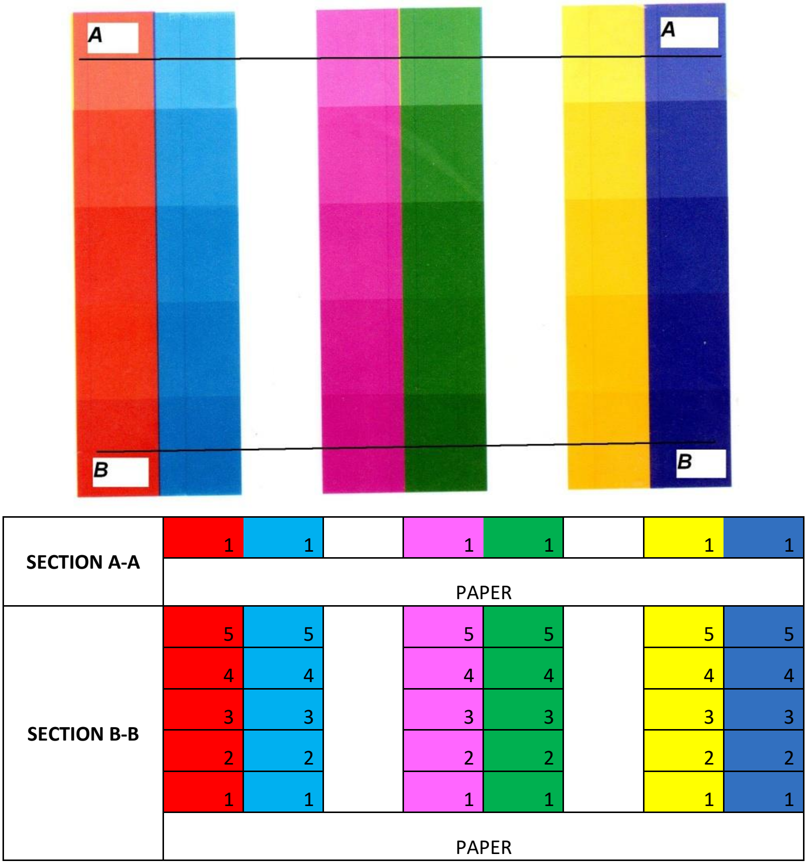


Figure 1 – Scheme describing the coating preparation of the samples of D method.

The second set of samples includes 45 samples repeated 5 times on 5 papers, called "Fingerprint", among primary and secondary hues in order to increase the statistics in terms of matching of the colour. The primary colours are very pure and this was verifying by microscope observation. The secondary ones are prepared mixing and overlapping the related primary hues. We calculated the average values for the 5 papers and we present overall only 60 samples for the fingerprint set. They are made with inkjet inks and they are coated on 80gr/mq papers. The samples have to be distinguish between those obtained by mixing and by overlapping. Furthermore, for this second set, we prepared samples with different optical density that starts from 10% and reaches 100% with the steps: 10%-25%-50%-75%- 100%. In the following text, the samples are indicated with two subscripts FP for indicate the group to which they belong (Fingerprint) and M or O to indicate the way with which they are prepared, respectively by mixing (M) or by overlapping (O). In the subscript for each sample is reported also the percentage of optical density. In order to explain this, the Figure 2 presents sections with maximum (A) and minimum (B). They correspond to maximum and minimum optical density set on printer and, in the same sample, also the difference between Oo/Vo/Go, respectively Orange/Violet/Green obtained with layers dry on dry overlapped versus OM/VM/GM respectively Orange/Violet/Green obtained from primaries mixing.

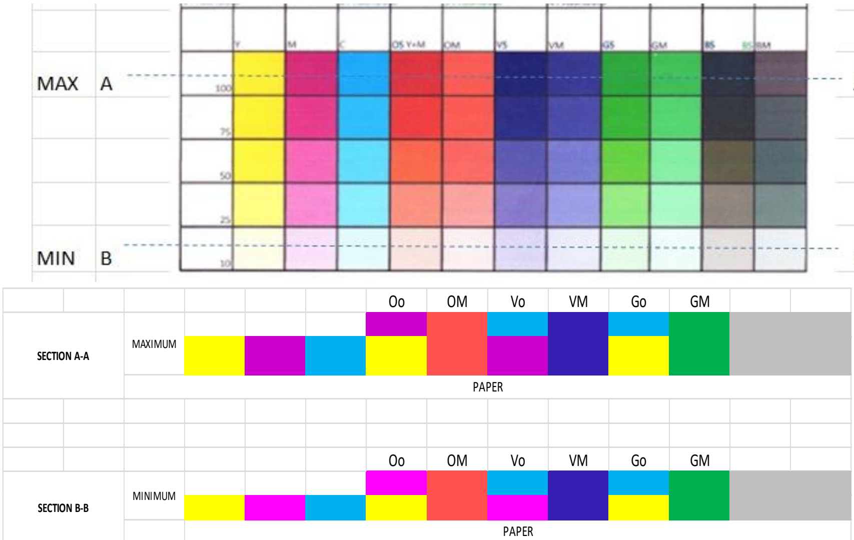


Figure 2 - Scheme describing the coating preparation of the Fingerprint samples set.

As is visible in the comparison reported in Figure 3, we have improved the quality of our samples. In particular, it is possible to put in evidence the differences between the oil based Ferrario green colour samples used in our last papers and the green Inkjet ink (present paper). As shown, the objective of increasing the homogeneity and of obtain a high level quality coating is reached.

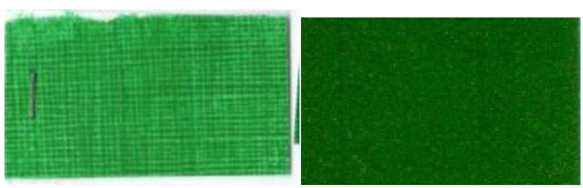


Figure 3 – The differences between the previous green sample and the most recent one obtained after an improvement of the colour materials and coating preparation.

The samples were prepared according to Schopenhauer directives [6] that are following: *"..Colours must be absolutely perfect, that is to say, such that they divide the whole activity of the eye without leaving an undivided residue, and are therefore free from any weakening or obscuration alien to their being, and are therefore extremely vivid and energetic colours. ; and besides they must be exactly 1/3, ½ and ¾ of the activity of the eye, and therefore perfect blue, red and yellow, that is to say the three basic chemical colours at the highest degree of purity "*. We followed what Schopenhauer said because it was necessary reach the maximum amount of hue in relating with minimum ones. Taking into account this, in the results section, we will put in comparison not only sum of complementary couples of maximum hue theorized and here verified but also their composition in the same sum for each colour using the representation suggested by Itten [3].

The spectrophotometric analysis

The spectrophotometric analysis was carried out in PH3DRA (Physics for Dating Diagnostics Dosimetry Research and Applications) Laboratories of Catania University & INFN section of Catania. The analysis was performed by Konica Minolta spectrophotometer, CM 2600d model, with measurement geometry d/8°, selecting an area of 6 mm in diameter (SAV, Small Average Aperture) following a specific standard protocol [5]. The results are related to the D65 illuminant and the CIE 1931 standard colorimetric observer (2° standard observer). It is normally used for the printing colour quality control. Data were obtained from repeated measurements (3 different acquisitions) and the elaboration regarded SPEX/100 values (SPecular component EXcluded and UV included). The acquisitions were made using software SpectraMagic® [7] and the data were elaborated with the Origin® software [8]. The scale adjustment represents a very important step and it was performed using the White Calibration Plate (CM-A145) as a target for the maximum lightness and the device CM-A32 for the minimum lightness. The results were elaborated focusing the Spectral Reflectance Factor (SRF %) trend in the visible region and the colour CIELAB coordinates [9].

3. Results and Discussion

In Table II the results for all 168 samples are reported. In particular, the data regard the colour coordinates and the related uncertainties and the calculated ΔE^*_{ab0}, $\Delta E^*_{ab0\%}$ and ΔE^*0 in 36 $_{ab}$ th.
The ΔE^*value with respect to the device for black used in the scale adjustment was calculated. In the following text, the ΔE^*such obtained is called ΔE_{*0}. In particular, first, the ΔE^*_{ab0} was calculated starting from the L*, a*, b* coordinates and then the percentage of each ΔE^*_{ab0} with respect to the sum of ΔE^*_{ab0} of the six colours. Then, the value of ΔE^*_{ab0} in thirty-sixths (ΔE^*_{ab0} in 36th) is reported.
The total uncertainty associated with each measurement was calculated according to the propagation uncertainty theory, as the square root of the squaring sum of standard deviation and instrumental error. This last contribution was estimated based on CIELAB coordinates measured on White Calibration Plate.
The high homogeneity and the coating high quality standard of the samples is verified through statistical analysis. In Figure 4 the histogram related to the frequency distribution of the ΔE^*_{ab}, for the samples belonged to the second set is presented. The L*a*b* values of the samples of the same type are very similar and it is possible to quantify trough the ΔE^*_{ab} that is less than the threshold of human eyes perception of the colour differences. On 225 measurements, the ΔE^*_{ab} values of 82% samples fall into the range 0-1.5, the 16% into the range 1.5-3.0 and 2% who remains into the range 3-5. The peak of reproducibility is about 0.5 and 1.0 with a frequency range of 40%.

The data illustrated in Tables II and III were elaborated as histogram (Figure 5). The histogram was realized starting from the values, obtained and then averaged, of the first and second samples set. In the same histogram, the theoretical values of Itten/Schopenhauer were listed.

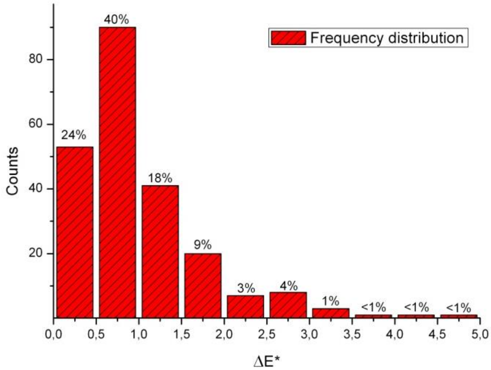


Figure 4 – Frequency distribution for samples belonged to the second set.

Table II – The average values and the related uncertainties of L*, a* and b*, the calculated ΔE^*_{ab}, ΔE^*_{ab0}, $\Delta E^*_{ab0\%}$ and ΔE^*_{ab0} in 36th and the values of Complementary Couples (CC) for the Samples (S) of the first set.

S	**L***	**δL***	**a***	**δa***	**b***	**δb***	**ΔE^*_{ab0}**	**$\Delta E^*_{ab0\%}$**	**ΔE^*_{ab0} in 36th**	**CC**	
Y_A1	84,7	2,5	-1,1	0,2	88,6	2,8	122,6	23%	8,4	13,3	Y+V
O_A1	53,3	1,8	46,8	1,7	52,1	1,7	88,0	17%	6,1	11,2	O+C
M_A1	34,5	1,0	70,1	2,0	-15,6	0,5	79,7	15%	5,5	11,4	M+G
V_A1	31,6	1,0	21,4	0,7	-59,8	1,8	70,9	14%	4,9		
C_A1	51,2	1,2	-29,1	1,4	-46,6	1,4	75,1	14%	5,2		
G_A1	51,1	1,8	-59,2	1,9	36,5	1,4	86,4	17%	5,9		
							522,7				
Y_A2	81,1	2,4	8,7	0,3	110,7	3,3	137,5	26%	9,4	13,9	Y+V
O_A2	42,3	1,5	59,3	1,9	56,7	1,7	92,3	17%	6,3	10,8	O+C
M_A2	41,3	1,5	73,0	2,2	-26,1	1,2	87,8	17%	6,0	11,3	M+G
V_A2	14,7	0,4	36,3	1,1	-53,0	1,6	65,9	12%	4,5		
Y_A2	81,1	2,4	8,7	0,3	110,7	3,3	137,5	26%	9,4	13,9	Y+V
O_A2	42,3	1,5	59,3	1,9	56,7	1,7	92,3	17%	6,3	10,8	O+C
M_A2	41,3	1,5	73,0	2,2	-26,1	1,2	87,8	17%	6,0	11,3	M+G
V_A2	14,7	0,4	36,3	1,1	-53,0	1,6	65,9	12%	4,5		
C_A2	41,2	1,2	-17,6	0,5	-48,4	1,5	65,9	12%	4,5		
G_A2	37,6	1,3	-58,1	1,9	36,9	1,2	78,4	15%	5,3		
							527,9				

S	L*	δL*	a*	δa*	b*	δb*	ΔE^*_{ab0}	$\Delta E^*_{ab0\%}$	ΔE^*_{ab0} in 36th	CC	
Y_A2	81,1	2,4	8,7	0,3	110,7	3,3	137,5	26%	9,4	13,9	Y+V
O_A2	42,3	1,5	59,3	1,9	56,7	1,7	92,3	17%	6,3	10,8	O+C
M_A2	41,3	1,5	73,0	2,2	-26,1	1,2	87,8	17%	6,0	11,3	M+G
V_A2	14,7	0,4	36,3	1,1	-53,0	1,6	65,9	12%	4,5		
C_A2	41,2	1,2	-17,6	0,5	-48,4	1,5	65,9	12%	4,5		
G_A2	37,6	1,3	-58,1	1,9	36,9	1,2	78,4	15%	5,3		
							527,9				
Y_A3	78,1	2,3	16,9	0,5	115,5	3,5	140,4	28%	10,1	14,7	Y+V
O_A3	35,3	1,1	63,1	1,9	50,9	1,6	88,4	18%	6,4	10,9	O+C
M_A3	35,3	1,4	70,2	2,2	-16,1	1,9	80,2	16%	5,8	10,4	M+G
V_A3	11,2	0,5	38,5	1,2	-49,2	1,5	63,4	13%	4,6		
C_A3	37,4	1,1	-12,0	0,4	-48,5	1,5	62,4	13%	4,5		
G_A3	30,6	1,0	-47,5	1,4	29,2	0,9	63,6	13%	4,6		
							498,4				
Y_B1	86,2	2,6	-3,5	0,2	70,8	2,6	111,6	22%	8,0	12,5	Y+V
O__B1	33,9	1,0	59,4	1,8	33,8	1,1	76,3	15%	5,4	11,1	O+C
M__B1	58,6	1,8	60,3	1,9	-27,7	0,8	88,5	18%	6,3	12,4	M+G
V__B1	42,1	1,4	-15,6	1,1	-44,4	1,4	63,1	13%	4,5		
C__B1	61,3	2,1	-31,6	1,0	-39,5	1,5	79,5	16%	5,7		
G__B1	50,8	1,7	-54,5	2,2	41,4	2,6	85,2	17%	6,1		
							504,3				
Y_B2	81,2	2,5	8,6	1,0	108,5	3,5	135,8	27%	9,8	14,1	Y+V
O_B2	37,6	1,4	61,2	2,0	46,3	2,7	85,5	17%	6,2	11,3	O+C
M_B2	41,4	1,2	71,7	2,2	-24,9	0,8	86,4	17%	6,3	10,6	M+G
V_B2	19,0	0,7	28,2	0,9	-47,2	1,6	58,2	12%	4,2		
C_B2	47,0	1,5	-23,1	0,9	-47,9	1,4	71,0	14%	5,1		
G_B2	31,5	1,7	-44,0	2,9	25,8	2,7	59,9	12%	4,3		
							496,8				
Y_B3	77,6	2,3	17,1	0,7	102,0	3,6	129,3	29%	10,6	14,2	Y+V
O_B3	32,2	1,0	55,7	7,0	32,4	16,0	72,0	16%	5,9	11,1	O+C
M_B3	57,6	1,8	47,0	3,2	-0,1	6,0	74,3	17%	6,1	10,7	M+G
V_B3	17,2	0,6	23,9	0,8	-32,6	1,2	43,9	10%	3,6		
C_B3	39,5	1,2	-13,4	0,4	-48,4	1,5	63,9	15%	5,2		
G_B3	29,7	1,1	-43,2	2,1	21,0	1,7	56,5	13%	4,6		
							440,0				
Y_C	87,2	2,6	-7,3	0,2	76,6	2,3	116,3	23%	8,5	12,4	Y+V
O_C	56,2	1,7	50,1	1,5	24,3	0,7	79,1	16%	5,8	11,6	O+C
M_C	49,4	1,5	65,6	2,0	1,4	0,2	82,1	17%	6,0	12,0	M+G
V_C	37,9	1,2	13,7	0,4	-36,4	1,1	54,3	11%	4,0		
C_C	59,8	1,8	-34,1	1,0	-42,3	1,3	80,8	16%	5,9		
G_C	62,6	1,9	-51,6	1,6	15,3	0,5	82,6	17%	6,0		
							495,1				
Y_D1	83,9	2,5	1,1	0,1	92,9	2,8	125,2	25%	8,9	13,6	Y+V
O_D1	49,9	2,2	49,1	3,3	46,3	1,6	83,9	17%	5,9	11,2	O+C
M_D1	57,1	1,7	55,1	1,7	-25,2	0,8	83,3	16%	5,9	11,2	M+G
V_D1	32,8	1,2	24,6	2,3	-52,9	1,6	66,9	13%	4,7		
C_D1	58,4	1,8	-22,3	0,8	-40,1	1,4	74,2	15%	5,3		
G_D1	47,8	1,4	-45,1	1,4	35,1	1,1	74,5	15%	5,3		
							508,0				

S	L*	δL*	a*	δa*	b*	δb*	ΔE^*_{ab0}	$\Delta E^*_{ab0\%}$	ΔE^*_{ab0} in 36th	CC	
Y_D2	81,5	2,5	9,0	0,3	105,1	6,2	133,3	27%	9,6	14,7	Y+V
O_D2	38,5	1,2	59,8	1,8	47,6	1,6	85,6	17%	6,2	11,1	O+C
M_D2	44,5	1,5	66,7	2,2	-24,6	0,8	83,9	17%	6,0	10,3	M+G
V_D2	15,1	0,7	38,9	1,3	-56,6	1,7	70,3	14%	5,1		
C_D2	45,7	1,4	-18,4	0,6	-47,5	1,4	68,5	14%	4,9		
G_D2	32,7	1,1	-40,6	1,9	26,7	1,0	58,6	12%	4,2		
							500,2				
Y_D3	79,4	2,4	14,6	0,4	105,5	3,3	132,8	29%	10,5	15,7	Y+V
O_D3	36,9	1,1	54,7	1,7	30,3	1,0	72,6	16%	5,7	10,8	O+C
M_D3	37,3	1,3	70,2	2,4	-19,5	0,6	81,9	18%	6,5	9,5	M+G
V_D3	11,6	0,4	40,9	1,3	-50,7	1,6	66,2	15%	5,2		
C_D3	39,0	1,2	-12,1	0,4	-48,8	1,5	63,6	14%	5,0		
G_D3	25,9	1,3	-25,9	1,9	13,3	0,8	39,0	9%	3,1		
							456,1				
Y_E1	89,0	2,7	-0,1	0,2	60,4	1,9	107,6	22%	8,0	13,0	Y+V
O_E1	60,4	1,8	32,7	1,1	18,8	0,7	71,2	15%	5,3	11,4	O+C
M_E1	64,0	1,9	45,6	1,4	-30,0	0,9	84,1	17%	6,3	11,6	M+G
V_E1	50,3	1,5	12,3	0,4	-42,9	1,3	67,2	14%	5,0		
C_E1	68,8	2,1	-20,7	0,7	-38,1	1,1	81,3	17%	6,1		
G_E1	60,7	1,8	-35,1	1,1	16,4	0,5	72,0	15%	5,4		
							483,4				
Y_E2	86,5	2,6	5,6	0,3	75,6	2,3	115,0	25%	8,9	13,5	Y+V
O_E2	51,1	1,5	40,8	1,2	24,3	0,7	69,8	15%	5,4	11,3	O+C
M_E2	55,1	1,7	51,7	1,6	-28,1	0,9	80,6	17%	6,3	11,2	M+G
V_E2	40,1	1,2	14,3	0,4	-41,2	1,2	59,2	13%	4,6		
C_E2	60,1	1,8	-20,0	0,6	-40,7	1,2	75,3	16%	5,8		
G_E2	50,2	1,5	-34,3	1,0	19,0	0,6	63,7	14%	4,9		
							463,6				
Y_E3	84,5	2,5	10,0	0,3	84,8	2,5	120,1	27%	9,7	14,0	Y+V
O_E3	45,8	1,4	44,7	1,3	25,4	1,0	68,9	15%	5,5	11,2	O+C
M_E3	50,0	1,5	53,7	1,6	-25,3	0,8	77,7	17%	6,2	10,8	M+G
V_E3	33,9	1,0	15,0	0,5	-38,7	1,2	53,6	12%	4,3		
C_E3	54,8	1,7	-18,2	0,5	-40,3	1,2	70,4	16%	5,7		
G_E3	43,2	1,3	-31,6	1,0	19,2	0,6	56,9	13%	4,6		
							447,5				
Y_E4	82,7	2,5	15,2	0,5	90,4	2,7	123,4	28%	10,0	14,2	Y+V
O_E4	45,8	1,4	44,9	1,4	28,5	0,9	70,2	16%	5,7	11,2	O+C
M_E4	46,2	1,4	54,4	1,7	-22,1	0,7	74,7	17%	6,1	10,6	M+G
V_E4	31,6	0,9	16,7	0,5	-36,5	1,1	51,1	12%	4,2		
C_E4	51,5	1,5	-16,6	0,5	-39,7	1,2	67,1	15%	5,5		
G_E4	42,2	1,3	-30,2	0,9	21,1	0,7	56,0	13%	4,6		
							442,6				
Y_E5	82,5	2,5	15,3	0,5	90,9	2,7	123,7	29%	10,4	14,5	Y+V
O_E5	42,9	1,3	46,1	1,4	26,3	0,8	68,2	16%	5,8	11,2	O+C
M_E5	43,6	1,3	54,3	1,7	-18,9	0,8	72,1	17%	6,1	10,4	M+G
V_E5	29,1	0,9	15,9	0,5	-33,9	1,0	47,4	11%	4,0		
C_E5	48,4	0,5	-15,1	0,5	-39,3	1,2	64,1	15%	5,4		
G_E5	38,7	1,2	-27,7	0,8	17,5	0,5	50,7	12%	4,3		
							426,4				

S	L*	δL*	a*	δa*	b*	δb*	ΔE^*_{ab0}	$\Delta E^*_{ab0\%}$	ΔE^*_{ab0} in 36th	CC	
Y_F	85,0	2,5	-4,9	0,1	91,8	2,8	125,2	23%	8,3	12,5	Y+V
O_F	50,0	1,5	57,6	1,7	53,8	1,7	93,4	17%	6,2	11,8	O+C
M_F	56,1	1,7	61,7	1,9	-20,3	0,6	85,9	16%	5,7	11,7	M+G
V_F	30,8	0,9	17,8	0,5	-50,7	1,5	62,0	11%	4,1		
C_F	61,9	1,9	-35,8	1,1	-44,0	1,3	84,0	16%	5,6		
G_F	47,9	1,4	-68,4	2,1	34,9	1,0	90,5	17%	6,0		
							540,9				
Y_G	85,7	2,6	-6,3	0,2	90,2	2,7	124,6	24%	8,6	12,0	Y+V
O_G	47,4	1,5	61,1	2,4	45,4	2,7	89,6	17%	6,2	11,9	O+C
M_G	48,2	1,4	68,7	2,1	1,0	0,0	84,0	16%	5,8	12,1	M+G
V_G	24,8	0,7	24,4	0,7	-35,1	1,1	49,5	9%	3,4		
C_G	62,8	1,9	-36,5	1,1	-38,5	1,2	82,2	16%	5,7		
G_G	54,4	1,6	-62,3	1,9	40,4	1,2	92,0	18%	6,3		
							521,8				
Y_H	84,8	2,5	-5,0	0,2	88,8	2,7	122,9	23%	8,4	11,9	Y+V
O_H	45,8	1,4	66,0	2,0	51,4	1,5	95,3	18%	6,5	12,0	O+C
M_H	47,5	1,4	70,2	2,1	2,6	0,1	84,8	16%	5,8	12,1	M+G
V_H	21,2	0,6	23,8	0,7	-39,6	1,2	50,8	10%	3,5		
C_H	60,3	1,8	-35,5	1,1	-40,7	1,2	80,9	15%	5,5		
G_H	52,3	1,6	-65,7	2,0	37,3	1,1	91,9	17%	6,3		
							526,7				

Table III – The average values and the related uncertainties L*, a* and b*, the calculated ΔE^*_{ab}, the calculated $\Delta E^*_{ab,}$ ΔE^*_{ab0}, $\Delta E^*_{ab0\%}$ and ΔE^*_{ab0} in 36th and the values of complementary couples for the Samples (S) of the second set.

S	L*	δL*	a*	δa*	b*	δb*	ΔE^*_{ab0}	ΔE^*_{ab0} %	ΔE^*_{ab0} in 36th	CC	
Y_FP100	86,7	2,6	0,5	0,1	75,1	2,3	114,7	24%	8,8	13,0	Y+V
O_FPM100	55,4	1,7	41,2	1,3	20,6	0,9	72,1	15%	5,5	11,6	O+C
M_FP100	44,9	1,4	51,3	1,8	-12,4	1,1	69,2	15%	5,3	11,4	M+G
V_FPM100	40,0	1,2	17,2	0,7	-33,8	1,2	55,1	12%	4,2		
C_FP100	61,2	1,9	-30,9	1,4	-38,6	1,2	78,7	17%	6,0		
G_FPM100	61,2	1,9	-46,8	1,4	16,4	0,8	78,7	17%	6,0		
							468,5				
Y_FP75	86,7	2,7	0,3	0,1	74,9	2,3	114,6	24%	8,5	13,1	Y+V
O_FPM75	55,2	1,7	41,3	1,3	20,8	1,0	72,0	15%	5,4	11,5	O+C
M_FP75	49,8	1,5	51,2	1,6	-15,7	1,1	73,2	15%	5,5	11,5	M+G
V_FPM75	45,9	1,5	17,4	0,7	-35,4	1,4	60,5	13%	4,5		
C_FP75	65,7	2,0	-30,5	1,5	-37,4	1,2	81,5	17%	6,1		
G_FPM75	66,6	2,0	-43,9	1,4	13,2	0,7	80,8	17%	6,0		
							482,5				
Y_FP50	87,3	2,7	-1,0	0,1	69,1	2,3	111,3	22%	8,0	13,1	Y+V
O_FPM50	58,5	1,8	38,3	1,2	18,1	1,0	72,2	14%	5,2	11,3	O+C
M_FP50	61,7	2,0	42,8	2,1	-19,6	0,9	77,7	16%	5,6	11,6	M+G
V_FPM50	60,8	2,6	14,2	0,9	-32,8	1,3	70,6	14%	5,1		
C_FP50	74,6	2,3	-25,1	1,3	-31,8	1,0	84,9	17%	6,1		
G_FPM50	76,2	2,3	-32,6	1,1	5,3	0,7	83,1	17%	6,0		
							499,7				

S	L*	δL*	a*	δa*	b*	δb*	ΔE^*_{ab0}	$\Delta E^*_{ab0\%}$	ΔE^*_{ab0} in 36th	CC	
Y_FP25	89,9	2,7	-3,4	0,4	39,5	2,3	98,3	20%	7,0	12,5	Y+V
O_FPM25	71,5	2,2	25,2	0,9	7,1	1,2	76,1	15%	5,4	11,7	O+C
M_FP25	69,7	2,3	34,9	1,7	-19,7	0,7	80,3	16%	5,8	11,9	M+G
V_FPM25	69,0	2,2	11,9	0,5	-29,4	1,1	75,9	15%	5,4		
C_FP25	80,5	2,5	-18,3	0,8	-26,8	0,8	86,8	17%	6,2		
G_FPM25	82,4	2,5	-22,2	1,0	-0,7	0,8	85,3	17%	6,1		
							502,8				
Y_FP10	93,2	2,8	0,2	0,3	2,7	0,9	93,2	17%	6,2	12,0	Y+V
O_FPM10	88,5	2,7	8,5	0,4	-6,7	0,8	89,1	16%	5,9	12,0	O+C
M_FP10	86,9	2,8	13,4	1,5	-14,9	0,9	89,2	16%	5,9	12,0	M+G
V_FPM10	86,4	3,5	6,0	0,7	-18,0	1,4	88,5	16%	5,9		
C_FP10	90,1	2,8	-3,9	0,5	-16,7	0,6	91,7	17%	6,1		
G_FPM10	91,2	2,8	-4,2	0,4	-8,8	0,7	91,7	17%	6,1		
							543,4				
Y_FP100	86,7	2,6	0,5	0,1	75,1	2,3	114,7	25%	9,2	12,9	Y+V
O_FPO100	44,7	1,4	45,9	1,5	16,6	1,2	66,2	15%	5,3	11,6	O+C
M_FP100	44,9	1,4	51,3	1,8	-12,4	1,1	69,2	15%	5,5	11,5	M+G
V_FPO100	32,8	1,0	14,4	0,9	-30,3	1,0	46,9	10%	3,7		
C_FP100	61,2	1,9	-30,9	1,4	-38,6	1,2	78,7	17%	6,3		
G_FPO100	53,9	1,7	-47,3	1,5	20,5	1,7	74,6	17%	6,0		
							450,2				
Y_FP75	86,7	2,7	0,3	0,1	74,9	2,3	114,6	24%	8,8	12,8	Y+V
O_FPO75	47,5	1,4	46,4	1,4	20,7	1,0	69,5	15%	5,3	11,6	O+C
M_FP75	49,8	1,5	51,2	1,6	-15,7	1,1	73,2	16%	5,6	11,7	M+G
V_FPO75	36,7	1,2	16,0	1,0	-33,1	1,1	52,0	11%	4,0		
C_FP75	65,7	2,0	-30,5	1,5	-37,4	1,2	81,5	17%	6,3		
G_FPO75	57,6	1,7	-46,6	1,5	26,8	2,0	78,8	17%	6,0		
							469,6				
Y_FP50	87,3	2,7	-1,0	0,1	69,1	2,3	111,3	23%	8,1	12,6	Y+V
O_FPO50	57,2	1,8	36,9	2,3	27,8	1,7	73,5	15%	5,4	11,5	O+C
M_FP50	61,7	2,0	42,8	2,1	-19,6	0,9	77,7	16%	5,7	11,8	M+G
V_FPO50	49,8	1,5	15,5	1,1	-33,8	1,3	62,2	13%	4,5		
C_FP50	74,6	2,3	-25,1	1,3	-31,8	1,0	84,9	17%	6,2		
G_FPO50	66,6	2,0	-38,9	1,3	35,4	1,6	84,8	17%	6,2		
							494,3				
Y_FP25	89,9	2,7	-3,4	0,4	39,5	2,3	98,3	20%	7,2	12,3	Y+V
O_FPO25	67,0	2,1	27,3	0,9	14,1	1,9	73,8	15%	5,4	11,7	O+C
M_FP25	69,7	2,3	34,9	1,7	-19,7	0,7	80,3	16%	5,9	12,0	M+G
V_FPO25	60,3	2,0	14,4	1,4	-30,9	1,1	69,3	14%	5,1		
C_FP25	80,5	2,5	-18,3	0,8	-26,8	0,8	86,8	18%	6,4		
G_FPO25	75,9	2,4	-29,3	1,0	18,4	1,8	83,5	17%	6,1		
							492,0				
Y_FP10	93,2	2,8	0,2	0,3	2,7	0,9	93,2	17%	6,3	12,0	Y+V
O_FPO10	85,8	2,7	10,4	0,6	-2,7	0,9	86,5	16%	5,8	12,0	O+C
M_FP10	86,9	2,8	13,4	1,5	-14,9	0,9	89,2	17%	6,0	12,0	M+G
V_FPO10	83,2	2,6	6,1	0,8	-19,8	0,7	85,8	16%	5,8		
C_FP10	90,1	2,8	-3,9	0,5	-16,7	0,6	91,7	17%	6,2		
G_FPO10	89,0	2,7	-7,6	0,7	-3,2	1,4	89,4	17%	6,0		
							535,7				

S	L*	δL*	a*	δa*	b*	δb*	ΔE^*_{ab0}	ΔE^*_{ab0} %	ΔE^*_{ab0} in 36th	CC	
Y_FP100	86,7	2,6	0,5	0,1	75,1	2,3	114,7	25%	9,2	12,9	Y+V
O_FPO100	44,7	1,4	45,9	1,5	16,6	1,2	66,2	15%	5,3	11,6	O+C
M_FP100	44,9	1,4	51,3	1,8	-12,4	1,1	69,2	15%	5,5	11,5	M+G
V_FPO100	32,8	1,0	14,4	0,9	-30,3	1,0	46,9	10%	3,7		
C_FP100	61,2	1,9	-30,9	1,4	-38,6	1,2	78,7	17%	6,3		
G_FPO100	53,9	1,7	-47,3	1,5	20,5	1,7	74,6	17%	6,0		
							450,2				

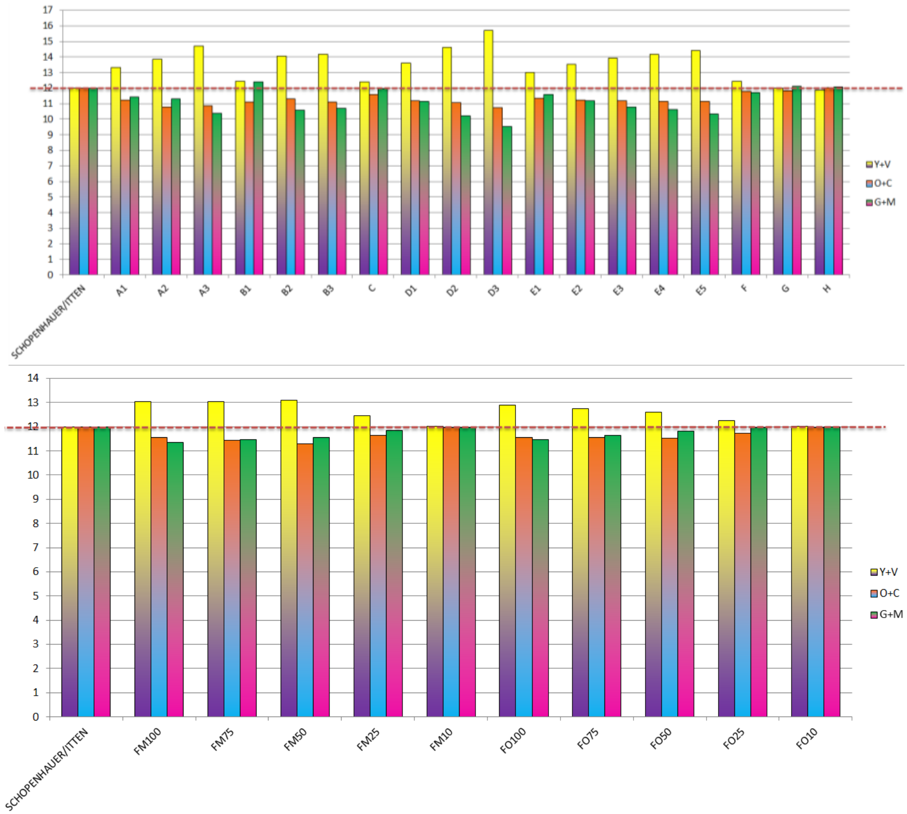
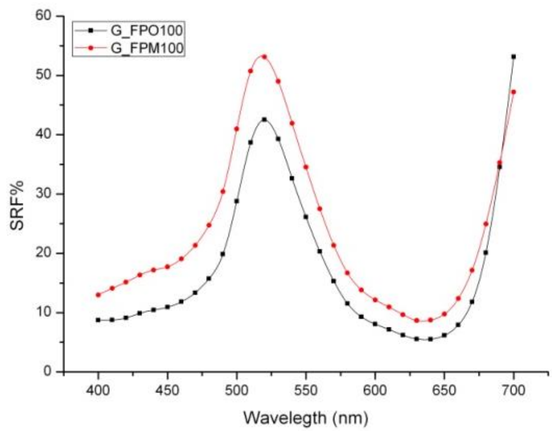


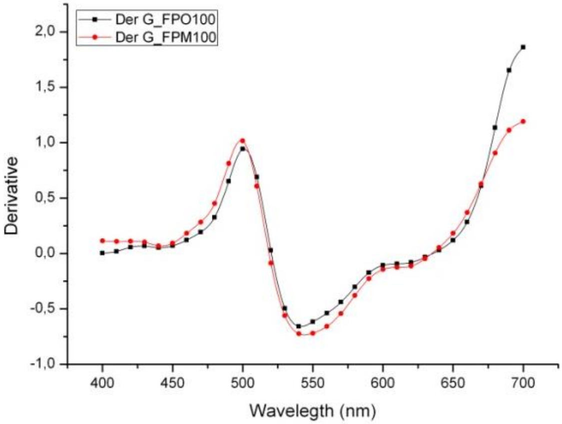
Figure 5 – Comparison of the experimentally calculated coefficients and the theorical coefficients of Itten/Schopenhauer.

Regarding the results of Table II and III, we can note that in 4 cases on 28 the ΔE^*a_{b0} in 36th values are less or equal or not greater then theorical values hypothesized that are evidenced in the Figures 4 and 5 with red arrows. Looking for reasons, we have verified that the samples, representing the 4 cases said below, are those obtained reducing the saturation of original colors. In particular, in the first two cases diluting with Ethilacetate for rotogravure printing and technological necessities, in the other two cases, reducing the optical density of inkjet printing. Furthermore, we observed that when the saturation increases the value of the sum of ΔE^*_{ab0} in 36th of complementary colors increases and, obviously, the more hue decreases the more the sum decreases. We can further make a conclusion that when the hue is the maximum

then the sum of values ΔE^*_{ab0} in 36th of couple Yellow and Violet is greater respect to others two.
The values indicated by Schopenhauer, 9: 8: 6: 3: 4: 6, as values in succession of YOMBCG, vary considerably depending on the coating method and other variables. However, certainly the value of the ΔE^*_{ab0} in 36th of the orange tendency is always significantly lower than the hypothesized one.
The secondary colors both mixed and overlapped behave in a similar way towards the sum of the ΔE^*_{ab} between complementary and confirm what has been supported up to now see Table II.
Another important result regards the comparison, from an optical point of view, between the secondary hues of the Fingerprint set obtained both by mixing and by overlapping the primary ones. In Figure 6a, 7a and 8a the Spectral Reflectance Factor trends in function of visible region of secondary samples, respectively G_FPO100 and G_FPM100, O_FPO100 and O_FPM100 and V_FPO100 and V_FPM100, are shown. As it is possible, to observe the trends are homothetic and the first derivatives (Figure 6b, 7b and 8b) are very similar. This outlines interesting perspectives regard the colour matching [10].
Resuming considerations of paragraph 2.1 regarding Schopenhauer indications, we have chosen just the maximum hue samples produced E5/FPM 100 and FPO100 and for these in Table IV and in Figure 9 we shown the comparison between the theorical and the experimental results obtained in this study.
On base of these results, we can conclude that for *maximum* hue of six colours used the diagram suggested from Itten [3] change like shown in Figure 10.

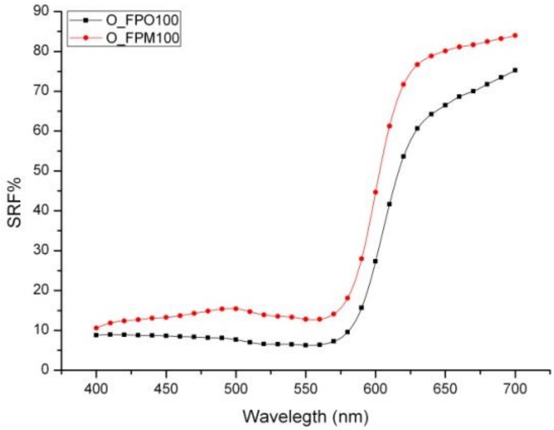


(a)

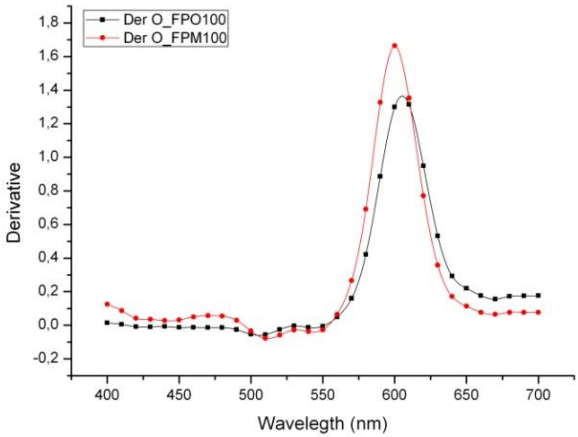


(b)

Figure 6 – Spectral Reflectance Factor trends (a) and the first derivatives (b) in function of the visible region for a Green sample of the second set obtained by mixing and by overlapping with optical density 100.

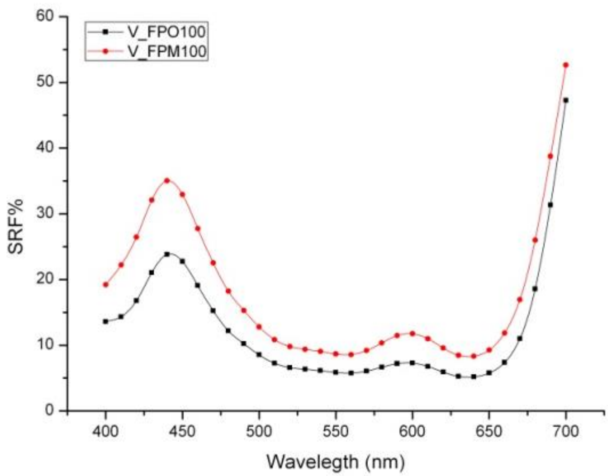


(a)

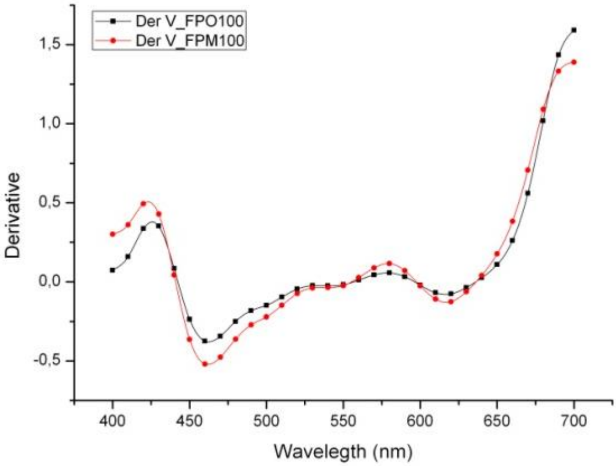


(b)

Figure 7 - Spectral Reflectance Factor trends (a) and the first derivatives (b) in function of the visible region for an Orange sample of the second set obtained by mixing and by overlapping with optical density 100.

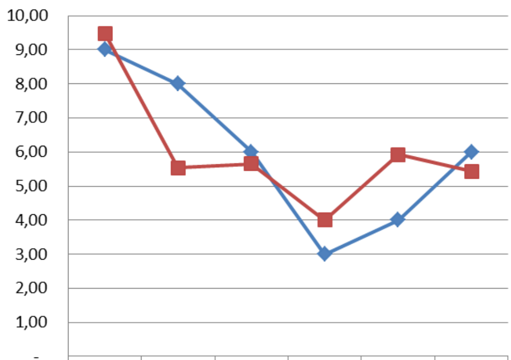


(a)



(b)

Figure 8 - Spectral Reflectance Factor trends (a) and the first derivatives (b) in function of the visible region for a Violet sample of the second set obtained by mixing and by overlapping with optical density 100.



	Y	O	M	V	C	G
Itten/Schopenhauer	9,00	8,00	6,00	3,00	4,00	6,00
Delta E*0 36TH AVERAGE	9,48	5,53	5,65	4,00	5,92	5,43

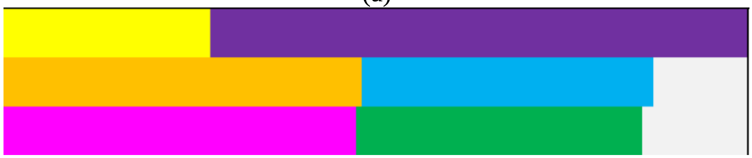
Figure 9 – Comparison between the Itten/Schopenhauer theorical *sestina* and the experimental values of ΔE^*_{ab0} in 36th average for the E5/FPM 100 and FPO100 samples.

Table IV – Comparison between Itten/Schopenhauer theorical *sestina* and theorical surface values and the corresponding ΔE^*_{ab0} in 36th complementary couple sum for each hue and the related experimental results obtained for the E5/FPM 100 and FPO100 samples.

Hue	**Itten/Schopenhauer**			**This study**		
	Theorical *sestina*	Theorical surface	Theorical Sum complementaries couples	ΔE^*_{ab0} in 36th average	ΔE^*_{ab0} surface	Complementary Sum ΔE^*_{ab0}36th
Y	9,00	3	12	9,5	4,0	13,5
O	8,00	4	12	5,5	5,9	11,4

M	6,00	6	12	5,6	5,4	11,1
V	3,00	9		4,0	9,5	
C	4,00	8		5,9	5,5	
G	6,00	6		5,4	5,6	

(a)



(b)

Figure 10 – (a) the representation of Itten/Schopenhauer *sestina* (b) the experimental one.

We can observe what we have verified:

- Sum of complementary hues coefficients ΔE^*_{ab0} in 36th are not equal for all of them and sum Yellow + Violet is greater than other two.
- Relationships of values of each colour in each sum is different respect those ipothized from Itten/Schopenhauer.
- If relationships are changed and are different from them reported by Itten and Schopenhauer, are these differences able to change our perception? Are the new relationships able to give us “more harmony and quiet” than old ones?

4. Conclusions

This study confirms paternity of statement on base of Itten colour quantity contrast is definitely to be attributed to Schopenhauer and not to Goethe like Itten reported.
New samples were prepared with a very good homogeneity and high quality, on different supports, with different type of inks and colours, mixed or overlapped, painted by hand or by drawdown bars, roto/flexo /inkjet printed.
Some small differences naturally are present but they are not achievable from normal human eye.
The sum of three pairs of complementary colours is not always constant, as supposed by Itten and Schopenhauer.
Even if theorical qualitative trend of sestina YOMVCG is confirmed, quantitative non-negligible differences were verified.
The results confirm furthermore that the sum of the complementary coefficient Y+V ΔE^*_{ab0} 36th is greater than the other two hypothesized and the average difference is not negligible.

Other new researches will be necessary and desirable in perception and psychological fields to verify effects of these new relationships among colours.

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Spline interpolation of Munsell data

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1. Introduction

The Munsell Color System (MCS), proposed by Albert Munsell in 1905, characterizes colors by three independent perceptual properties - Hue, Value and Chroma, which represent tint (e.g. red, yellow, blue or green), lightness, and difference from neutral grey, respectively [1][2]. To match or specify the color appearance of objects by the MCS, a set of reference physical samples (Munsell Atlas, or "The Munsell Book of Color") was released in 1915, commercialized in 1929, and updated in 1943 [1][3]. Owing to its effectiveness and simplicity, the MCS is still used in many different application areas, such as color design, soil analysis, forensic pathology, and many others [1].

An important problem in color applications is the conversion between MCS specifications and CIE *Yxy* coordinates [3][4]. This specific task has been widely discussed and investigated in the scientific literature, and is addressed in standard body specifications [3]-[9]. Unfortunately, no closed form expression is available today to convert Munsell data to CIE notations directly [5][9]. Thus, such conversion is usually performed by tri-dimensional interpolation techniques based on the so-called Munsell Renotation Data (MRD), i.e. a set of color samples provided in [3], for which both Munsell specifications and CIE coordinates are given.

Besides MRD, [3] also proposed a visual interpolation method based on maps of *xy* coordinates with manually drawn curves passing through the MRD points, and representing loci of constant-chroma and constant-hue in the MCS space. Both this method and the MRD have been included in the ASTM standard D1535, "Standard Practice for Specifying Color by the Munsell System" [4].

The visual procedure proposed in [3], however, results impractical in most applications, in particular when a considerable amount of color data must be processed [5]. Hence, various computer based conversion tools have been developed, which can digitally perform both the Munsell-to-CIE ("interpolation") and the CIE-to-Munsell ("inversion") data conversion [5]-[8].

Computer programs for Munsell data interpolation typically adopt a tri-dimensional search-and-interpolate approach; most of them rely on linear interpolation techniques. However, although several closed software implementations and open algorithms are now available [10]-[12], to the best of the authors' knowledge the most popular technique is the one presented in [5]. Available in Matlab, Octave and Python languages as open source [6][7], this algorithm performs linear or radial interpolation between pairs of MRD points according to their position in the MCS space, approximating by digital means the manually drawn curves of the ASTM standard [4].

In this context, the contribution of this paper is a comparison of three Munsell data interpolation techniques, namely the commonly used linear interpolation approach, the linear/radial interpolation proposed by [5], and a novel Munsell-to-CIE conversion algorithm, proposed in this paper and based on the spline interpolation technique [13].

To the best of the authors' knowledge, spline interpolation has never been applied to Munsell data processing. This technique can provide a smooth, piecewise polynomial function, called "spline", passing through a set of given knots and minimizing the average curvature [13]. In the past, the term "spline" indicated the elastic rulers that were used to producing smooth curves in technical hand-drawing. Thus, the idea behind the application of spline interpolation to Munsell data, is to obtain digital curves that result closer to the hand-drawn ones given in [3], and still used today to performing the standard visual interpolation procedure according to [4].
A second objective of the paper is to overcome a practical limitation that presently affects [5]. Such algorithm, in fact, at least in the version available at the time when this paper was written, cannot convert Munsell specifications with Chroma lower than 2. Conversely, the proposed procedure can straightforwardly provide results for any Chroma; hence, it can be useful in those applications in which low Chroma colors are used.
The structure of the paper is as follows. In the next section, we give a brief survey of the related work available in the literature. Section 3 introduces the proposed spline interpolation technique for Munsell data, while Section 4 presents simulation results with the comparison of linear, linear/radial and spline Munsell data interpolation techniques.

2. Related work

The first visual technique to convert Munsell specifications to CIE *Yxy* coordinates, and viceversa, was proposed by Newhall, Nickerson and Judd in 1943 [3]. In their work, Newhall and co-authors analyzed the first set of 1943 Munsell color samples released in 1929 in the "Munsell Book of Colors"; in particular, they revised such data through subjective tests, and extended them with additional samples. Thus, they provided the so-called Munsell Renotation Data (MRD), i.e. a collection of 2473 Munsell specifications, whose corresponding CIE *Yxy* coordinates (relative to Illuminant C) were obtained through instrumental measurements. Such results have then been included in the ASTM standard [4]. The focus of this paper is the analysis of different interpolation techniques applied to such reference data. For the sake of brevity and clarity, other important related problems, such as the analysis of the interpolation problem under different illuminants, will not be considered in the following.
The 2473 MRD samples give the CIE *Yxy* equivalents for 40 Munsell Hues at steps of 2.5 (e.g., 2.5R, 5R, 7.5R, 10R, etc.), for 9 integer Values (1 to 9), and for Chroma at integer multiples of two, starting from 2 up to the Mac Adam limits [3] [14].
The 1929 data, the updated data (i.e. the MRD released in [3]), and an extended version of the MRD, including Dark Color samples [15] and extrapolated colors (eventually "unreal", i.e. beyond the Mac Adam limit) to be used for interpolation of Munsell specifications close to the MacAdam limit, are available in digital format at [14].
In [3], graphical techniques for both color data interpolation and inversion are given. However, since this paper focuses only on the interpolation problem, in the following the analysis of the contributions available in the literature will be limited to this aspect.

The Munsell data interpolation problem can be stated as follows. Given a Munsell specification pHV/C, with Hue pH (where p is a real number in (0,10], while H is a letter in {R,YR,Y,GY,G,BG,B,PB,P,RP}, [3]), Value V and Chroma C, not included in the MRD set, find the corresponding CIE Yxy coordinates:

$$\begin{aligned} Y &= f_1(pH,V,C) \\ x &= f_2(pH,V,C) \\ y &= f_3(pH,V,C). \end{aligned} \tag{1}$$

In (1), it is assumed that the CIE x,y,Y coordinates can be expressed as a function $f = (f_1,f_2,f_3)$ of Munsell Hue, Value and Chroma. However, although some results that aim at approximating $f = (f_1,f_2,f_3)$ in closed form are available [9], to the best of the authors' knowledge, only search and interpolate techniques are at present in use to perform Munsell data interpolation.

The $Y = f_1(pH,V,C)$ coordinate, although expressed in (1) as a function of pH,V,C, indeed depends only on the Munsell Value, and is independent of Hue and Chroma, i.e. $Y = f_1(V)$ [3]. An updated expression to directly evaluate Y from V, based on a fifth order polynomial, can be found in [4], (Eq.2).

To obtain the CIE chromaticity coordinates xy using the MRD, [3] suggests a visual approach for the case of integer Value Munsell specifications. As an example, Fig.1 shows the subset of MRD with Value equal to 5, represented on the CIE xy plane. One can clearly identify the ovoidal closed curves that, on such a plane, represent the constant-chroma loci, and the radial curves originating from the Illuminant C neutral point outwards, that represent the constant-hue loci [3]. Fig.2 shows the same data, with the constant-chroma and constant-hue loci passing through the MRD manually drawn, as provided by [3] and [4]. For each integer Munsell value from 1 to 9, [3] and [4] provide graphical maps like the one in Fig. 2, to support the visual conversion process.

In [3], the Munsell to CIE conversion problem for the case of non-integer Value is then solved by linear interpolation. In particular, for a Munsell specification (pH_r,V_r,C_r), with non-integer V_r Value, visual interpolation is at first carried out for the two consecutive integer values V_{floor}, V_{ceil}, such that $V_{floor} < V_r < V_{ceil}$. Once determined the coordinates (x_{floor},y_{floor}) (x_{ceil},y_{ceil}) of (pH_r,V_{floor},C_r) (pH_r,V_{ceil},C_r), the CIE coordinates (x_r,y_r) can be evaluated by linear interpolation. Expressions and a discussion on this aspect can be found in [5], (Par. 3.2, Eqs. 23 and24). To the best of the authors' knowledge, all software interpolation techniques adopt the same approach to deal with non-integer Munsell Value. As a consequence, in the following we will make the further simplification of considering only integer Munsell Values, and rely on linear interpolation for the non-integer Value case.

To overcome the practical limitations of the visual interpolation technique in [3][4], various algorithms have been proposed through the year, starting from the first computer-based technique presented in [6]. Such algorithms aim at implementing in software the procedure standardized in [3][4], mainly by applying linear interpolation techniques. For the sake of brevity, in the following we will summarize and discuss only the interpolation algorithm described in [5], taken from the Munsell and

Kubelka-Munk Toolbox (MKT) Open Source project [12], for the case of Munsell color data with integer Value.

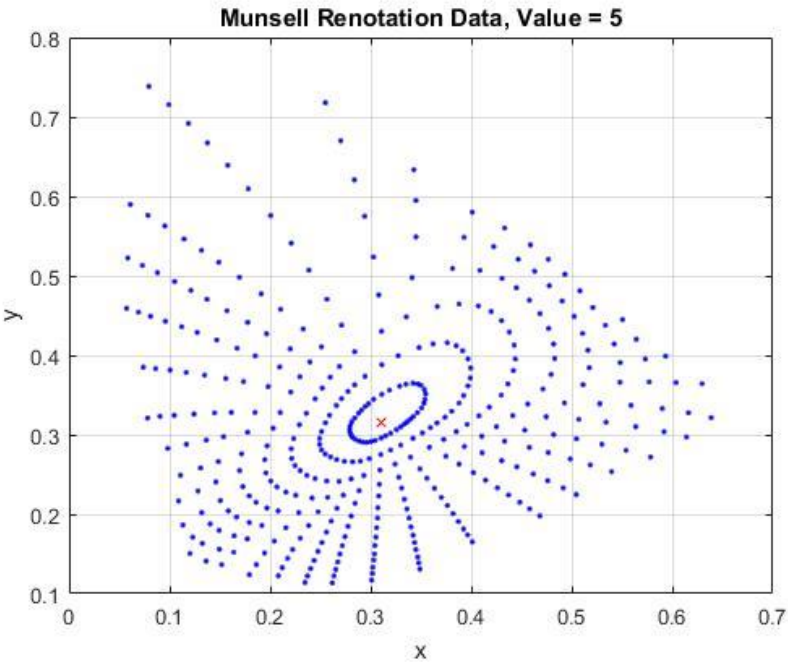

Fig.1 Munsell Renotation Data with Munsell Value equal to 5 (blue poins), represented on the CIE xy plane. The Illuminant C neutral origin point is indicated with a red cross.

2.1 The MKT interpolation algorithm

The MKT algorithm, in its first step, calculates via linear or radial interpolation the CIE *xy* coordinates of a Munsell specification *pHV/C* with generic Hue, integer Value, and Chroma equal to a multiple of two. The generalization to a color with any Chroma will be considered later.

MKT retrieves the two consecutive MRD samples p_1H_1V/C and p_2H_2V/C adjacent to *pHV/C*, and their corresponding *xy* coordinates (x_1,y_1) and (x_2,y_2). Notice that *pHV/C*, p_1H_1V/C and p_2H_2V/C have the same Chroma *C*, hence they lie on the same costant-chroma locus. In the following, p_1H_1V/C and p_2H_2V/C, will be indicated as "adjacent MRD samples". For instance, if the Munsell specification to be converted is 6R5/4, its adjacent MRD samples are 5R5/4 and 7.5R5/4,with *xy* coordinates equal to (x_1,y_1) = (0.3740,0.3220) and (x_2,y_2) = (0.3806,0.3294).

To determine if linear or radial interpolation should be applied, a lookup table is used, indicating the segments of the MRD constant-chroma loci that should be radially interpolated (see [5], Table I, page 8). Linear or radial interpolation is then applied to the two adjacent MRD samples.

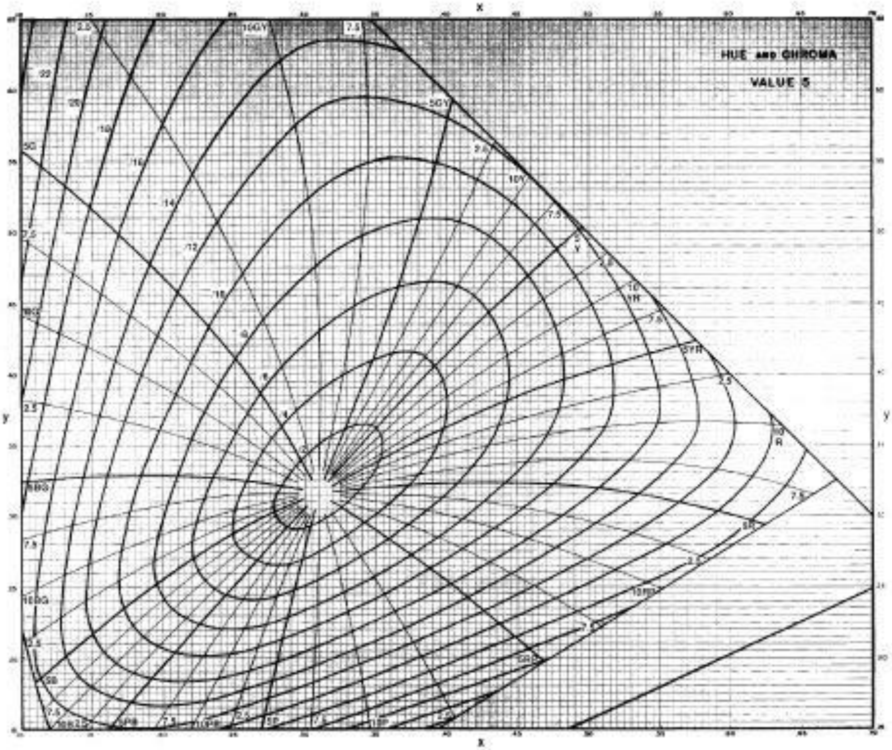

Fig.2 Munsell Renotation Data with Munsell Value equal to 5, manually drawn constant-hue and constant-chroma loci (from [4], Fig.7)

2.1.1 Linear Interpolation

In the case of linear interpolation, the algorithm continues transforming Hues, such as 6R or 5PB, into real numbers, typically in the range (0,100], as suggested by the ASTM standard [3] ("ASTM numeric Hue", see Fig.1 in [3]), or in the range (0,10], as in the Matlab implementation of MKT [12]. Linear interpolation is then applied, using the adjacent MRD sample coordinates (x_1,y_1) and (x_2,y_2). For instance, the CIE coordinates (x,y) of the Munsell color 6R5/4 are calculated by the following expression:

$$(x, y) = \frac{H2-Hx}{H2-H1}(x1, y1) + \frac{Hx-H1}{H2-H1}(x2, y2) = (0.3767{,}0.3248) \qquad (2)$$

where $H2$=7.5, $H1$=5 and Hx=6 are the ASTM numeric Hues of p_1H_1 = 7.5R, p_1H_1 = 5R, and pH=6R, respectively [4].

2.1.2 Radial Interpolation

For radial interpolation, the xy coordinates (x_1,y_1) and (x_2,y_2) of the adjacent MRD samples p_1H_1V/C and p_2H_2V/C must be transformed into polar coordinates ($\theta1$,$\rho1$) and ($\theta2$,$\rho2$), with respect to the the Illuminant C neutral point

(x_0=0.31006,y_0=0.31616). In this case, MKT also transforms Hues in angles, rather than ASTM numeric hues. In the Matlab MKT implementation [12], this task is performed by the `MunsellHueToChromDiagHueAngle` function, which returns a quantity between 0 and 360 degrees, referred to as Temporary Hue Angle, and here indicated with the symbol *TH*.

TH is evaluated for the adjacent MRD samples and the Munsell specification to be converted, thus obtaining *TH1*, *TH2* and *TH*, respectively. The polar coordinates of *pHV*/*C* are obtained as:

$$(\theta, \rho) = \frac{TH2 - THx}{TH2 - TH1}(\theta 1, \rho 1) + \frac{THx - TH1}{TH2 - TH1}(\theta 2, \rho 2), \tag{3}$$

And are finally transformed in *xy* coordinates.

2.1.3 Interpolation with generic Chroma

To interpolate a Munsell specification *pHV*/*C* with generic Chroma, the MKT algorithm first calculates the coordinates of the Munsell specifications with the same Hue *pH* and Value *V*, and multiple-of-two Chroma *C*1, *C*2, such that $C1 < C < C2$. The *xy* coordinates of *pHV*/*C* are obtained by linear interpolation as from the coordinates (x_1,y_1) and (x_2,y_2) of such points as:

$$(x, y) = \frac{C2 - Cx}{C2 - C1}(x_1, y_1) + \frac{Cx - C1}{C2 - C1}(x_2, y_2) \tag{4}$$

2.1.4 Reference test samples

Comparing different interpolation techniques requires the availability of reference color samples, not included in the MRD, for which both the Munsell specifications and the corresponding CIE *Yxy* coordinates are *a priori* known.

In the literature, however, only few examples of such test samples are available. In [6], for instance, the conversion algorithm is thoroughly described, but no conversion example is provided. In [8], the test reference data were obtained by graphical interpolation performed by the authors according to [4]. In [5], test samples given in previous papers (such as [8]) and in [4], or obtained by commercial software, are used. However, the reported experiments are mainly focused on the inversion problem, rather than on interpolation. The ASTM standard [4] provides a Table with CIE data converted graphically to Munsell notation ([4], Table 4, page 27), that should be used to verify the accuracy of data obtained by computer conversions. However, such Table contains only 4 samples, and none of them has Chroma lower than 2, as required by the work described in this paper.

To overcome the lack of an adequate test sample set, this paper will use the series of color samples known as “Munsell 100-Hues at 5/5” that was originally intended for internal use in the Munsell Laboratory. Such data, together with other interesting series, are given in [16], Table III, page 382. In this work, such series has been expanded with a subset of the Weak Chroma data set, given in [16], Table III, page 384.

3 Spline interpolation of Munsell data

To introduce Munsell data spline interpolation, we will first consider the case of Munsell Chroma equal to a multiple of two, as in the MKT algorithm description. The basic idea is to express the (*x*,*y*) coordinates of a given constant-chroma locus (an "ovoid"), identified by integer Value *V* and multiple-of-two Chroma *C*, in parametric form as:

$$x = g_1(H|V,C),\ y = g_2(H|V,C) \tag{5}$$

In (4), for a given ovoid, only the ASTM numeric Hue *H* changes, while both *V* and *C* remain necessarily constant. Thus, in the following, we will omit *V* and *C*, and express *x* and *y* as $x = g_1(H)$ and $y = g_2(H)$. Under the given assumptions, from (5) one could directly obtain the *xy* coordinates of a Munsell specification from its ASTM numeric Hue *H*. Unfortunately, the functions g_1, g_2 are not known, except at a finite number of data points corresponding to the MRD samples, where $x_i = g_1(H_i)$, $y_i = g_2(H_i),\ i = 1,2,$....*N*, and x_i, y_i, H_i are known and available from [4]. For the sake of simplicity, this paper will consider only the case of constant-chroma locii entirely within MacAdam limits; hence, in the following, *N* will always be equal to 40 [4].
To evaluate the *xy* coordinates of interest, in (5) the unknown functions g_1, g_2 can be substituted by their approximations $\hat{g}_1$, $\hat{g}_2$, obtained by applying spline interpolation techniques to the specific subset of the MRD corresponding to the constant-chroma locus of interest. This way, $\hat{g}_1$, $\hat{g}_2$ are piece-wise cubic polynomial approximations of g_1, g_2, passing through the MRD coordinates, and continuous up to the second derivative [13].
The procedure to interpolate a Munsell specification (*H*,*V*,*C*), with *V* integer and *C* multiple of 2, can thus be summarized as follows. At first, one determines the constant-chroma locus on which the specification lies, and retrieves from the MRD the corresponding *xy* coordinates (x_i,y_i) and numeric Munsell Hues H_i. Such quantities are then collected in three vectors $\boldsymbol{x}=[x_1,\dots x_N]^T$, $\boldsymbol{y}=[y_1,\dots y_N]$, $\boldsymbol{H}=[H_1,\dots H_N]$.
The *xy* coordinates can be calculated as:

$$x = \hat{g}_1(H), y = \hat{g}_2(H) \tag{6}$$

where

$$\hat{g}_1 = spline(\boldsymbol{H},\boldsymbol{x}),\ \hat{g}_2 = spline(\boldsymbol{H},\boldsymbol{y}); \tag{7}$$

In (7), $q = spline(\boldsymbol{t},\boldsymbol{z})$ represents the cubic spline interpolant polynomial *q* of the data values **z**, at data sites **t**. Notice that (7) does not reflect the fact that the MRD ovoids are closed curves, hence with coincident endpoints such that $g_1(0) = g_1(100)$ and $g_2(0) = g_2(100)$. This could result in an interpolated curve not smooth at *H*=0 and *H*=100. To solve this problem, the vectors **x**, **y** and **H** have been extended by wrapping their first and last three elements. For instance, the vector **x** is transformed into $\boldsymbol{x}'=[\ x_{N-2}, x_{N-1}, x_N, \boldsymbol{x}^T, x_1, x_2, x_3\ ]^T$. The interpolation procedure is thus performed by using (6),(7), with **x'**, **y'** and **H'** taking the place of **x**, **y** and **H.**

3.1 Interpolation with generic Chroma

To interpolate a Munsell specification *pHV/C* with generic chroma *C*, the proposed algorithm determines at first the coordinates of a sequence of constant-hue points with Hue equal to *H*, and increasing Chroma equal to 2,4,…,C_M, using the procedure described in the previous paragraph. The neutral point is also considered, as Munsell Value with specifications *pHV*/0 and *xy* coordinates (0.31006, 0.31616). The obtained coordinates and the considered multiple-of-two Chromas are then organized in three vectors $\boldsymbol{x}=[x_1,\dots x_M]^T$, $\boldsymbol{y}=[y_1,\dots y_M]$, $\boldsymbol{C}=[C_1,\dots C_M]$. In the examples discussed in the following a value of M=7 was used, i.e. $\boldsymbol{C}$=[0,2,4,6,8,10,12]. The final coordinates are calculated by spline interpolation as:

$$x = \hat{h}_1(C),\, y = \hat{h}_2(C) \tag{8}$$

where

$$\hat{h}_1 = spline(\boldsymbol{C}, \boldsymbol{x}),\ \hat{h}_2 = spline(\boldsymbol{C}, \boldsymbol{y}); \tag{9}$$

4 Numerical results

To compare the results of linear, linear/radial and spline interpolation, three Matlab algorithms have been used. The algorithm described in [5] and available in [12] was used for linear/radial interpolation; this algorithm was then modified for the linear interpolation experiments. Finally, a spline interpolation algorithm was written based on (6)-(9) and the procedures described in the previous section. Such algorithms were applied to the Munsell 100-Hues at 5/5 series (Munsell 5/5) described in Par. 2.1.4.

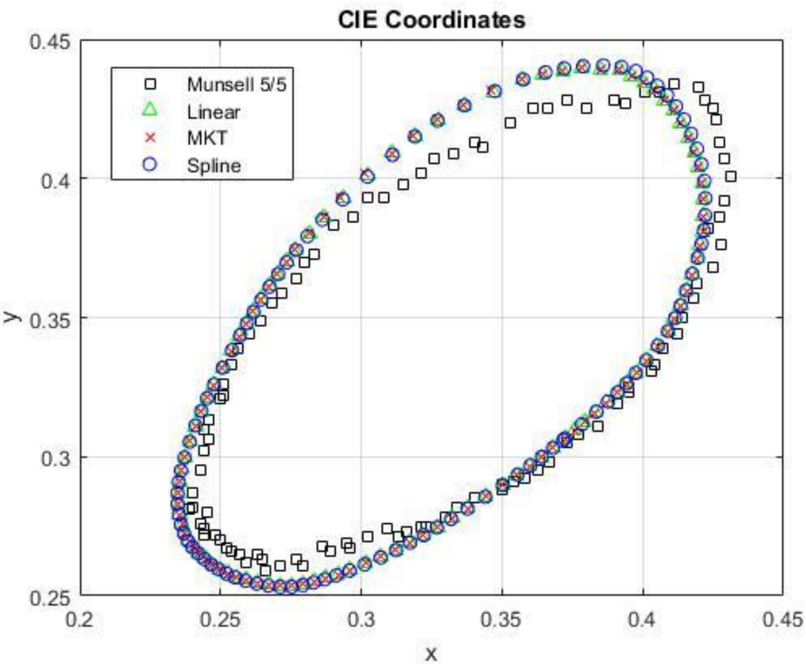

Fig.3 CIE coordinates of the 100 Munsell 5/5 series, and obtained with the Linear, MKT and Spline algorithms.

Fig.3 shows the CIE *xy* coordinates of the 100 Munsell 5/5 series, given by [16] (black squares). Moreover, also the coordinates obtained by applying the Linear, MKT and Spline interpolation algorithms to such series are reported. One can immediately see that the behavior of the three algorithms is quite similar. However, some discrepancies can be observed with respect to the Munsell 5/5 reference curve [16], in particular in the upper-right corner region, and in the left lower corner. Moreover, while the interpolated values provide smooth curves, the reference Munsell 5/5 samples provide a quite irregular constant-chroma locus.

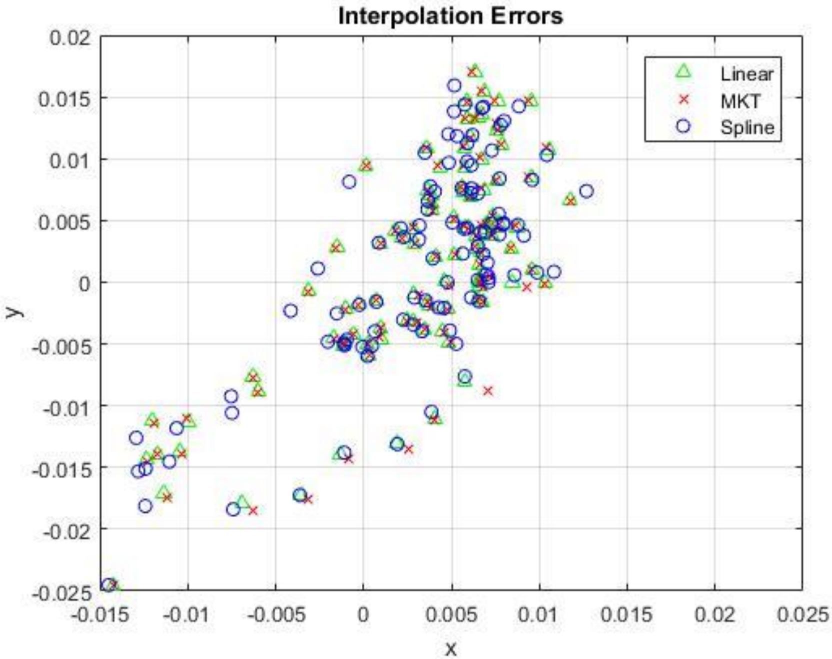

Fig.4 Interpolation errors obtained with the Linear, MKT and Spline algorithms.

In Fig.4 the error distribution of the three algorithm with respect to the reference coordinates is shown. Even if Fig.4 confirms the similar behavior of the three techniques, in some cases the spline algorithm data differ from the often coincident results of the linear and MKT algorithm. Also, all three techniques exhibit errors which do not cluster around the null point. Some synthetic statistical indexes summarizing such behaviors are reported in Tab.1.

Algorithm	**Mean Error x, y**	**RMSE**	**Max Err. (Eucl.)**	**CIEDE2000**
Linear	0.0034, 0.0014	0.0109	0.0284	5.02
MKT	0.0034, 0.0013	0.0109	0..0284	5.02
Spline	0.0033, 0.0013	0.0111	0.0290	1.83

Tab. 1 – Interpolation results for Munsell 5/5 samples, statistical indexes

The second and third columns of Tab.1 report the interpolation error mean and Root Mean Square Error (RMSE) for the 100 samples of the Munsell 5/5 series, provided by the three techniques. It can be clearly seen that the behavior of the analyzed algorithms is very similar. The fourth column reports the maximum error observed in the 100 performed interpolations, evaluated as the maximum Euclidean distance between the reference and the interpolated values. The maximum error occurs for the Munsell color 5GY5/5 when the Linear and MKT algorithms are used; for 1R5/5 for the spline algorithm. Although the maximum error occurs for different color samples, the Euclidean distances between interpolated and reference coordinates in the two cases are very close.
In the analysis, simulations were also performed adopting the CIEDE200 color difference, thus using a different metric besides the Euclidean distance. To this end, the fifth column of Tab.1 reports the CIEDE2000 color difference between the reference and the interpolated *Yxy* coordinates of sample 5GY5/5 for the Linear and MKT algorithm; of sample 1R5/5 for the spline algorithm [17]. One can observe that, even if the corresponding Euclidean distances are close, this CIEDE2000 based statistical index for the Linear and MKT algorithms results significantly higher than for the spline algorithm. To give an indicative reference, the CIEDE2000 perceptual difference between 5GY5/5 and the consecutive color 6GY5/5 in the Munsell 5/5 series is 1.51, while between 1R5/5 and 2R5/5 is 2.35. To arrive at any conclusion about the actual behavior of the considered algorithms when the CIEDE2000 metric is used, a much wider set of tests should be carried out. However, the use of different metrics in Munsell data interpolation is a problem that goes beyond the scope of this paper, and will be not further considered in the following.
Tab.2 reports the reference and interpolated values for five samples taken from the Weak Chroma series given in [16]. The results in this case are in line with those obtained for higher Chroma values.

Munsell Notation	Reference x	Reference y	Spline x	Spline y
5R5/1	0.333	0.319	0.323	0.318
5Y5/1	0.332	0.343	0.330	0.339
5G5/1	0.300	0.326	0.304	0.327
5B5/1	0.286	0.305	0.295	0.310
5P5/1	0.306	0.298	0.307	0.305

Tab. 2 – Spline Interpolation results for low Chroma samples

5. Conclusions

This paper has presented a comparison of three different algorithms that can perform Munsell data interpolation, based on the Munsell Renotation Data. The first algorithm adopts a purely linear interpolation approach, while the second one applies linear or radial interpolation, depending on the position of the Munsell color in the MCS space.

The third algorithm is a novel one proposed in this paper, based on spline interpolation. The reference data set used in the simulations was the 100 Munsell 5/5 series. The three algorithms provide similar results, and smooth costant-chroma locii. The spline results are in some cases different from the almost coincident linear and linear/radial results. Conversely the reference 100 Munsell 5/5 gives an irregular constant-chroma locus, which renders quite problematic the accuracy analysis of the three algorithms.
Thus, the problem of analyzing the accuracy provided by the three algorithms and comparing their results is still open. The spline interpolation technique proposed in this paper can interpolate also Munsell specifications with Chroma lower than two. The open source linear/radial algorithm analyzed in the paper, at least in the open source version available when this paper was written, can interpolate only Munsell specifications with minimum Chroma equal to two.

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2. Colour and Digital

SHAFT (SAT & HUE Adaptive Fine Tuning), a new automated solution for target-based color correction

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1. Introduction

To estimate the sensitivity functions of the camera, many computational camera calibration models were developed [1, 2], but, of course, target-based 'color correction' is today the most common technique to obtain a faithful reproduction of color in many fields where the digital photography is used: portraiture, fashion, furniture design, interior design Architectural Heritage (AH) and Cultural Heritage (CH).
This technique establishes the color relationship according to a set of color patches with available pre-measured spectral or colorimetric data as specified by ISO17321.14 [3], allowing to have color corrected images using a limited set of parameters and subtle variation of color according with well-defined effects.
However, results are illuminant specific [4], very sensitive to the technique used and to operator errors in the capture process; moreover, they could be erroneously affected by non-uniformity lighting on the chart, incorrect framing, and flare [5].
A last issue concerns the acquired target. In the target-based characterization method, the relationship between the spectral responsivities of the camera and the CIE color matching functions is established according to a set of color patches with available pre-measured spectral or colorimetric data. The material aspects become particularly important when color patches vary in surface and spectral properties, leading to different appearance changes according to geometry changes. This dependence had led to designing optimized color targets in recent research, considering several factors, such as material, gamut, and the number of color patches.
Despite these problems target-based 'color correction' had in the last years a growing success, essentially due to its flexibility and easy to use: it involves on the field a simple capture of an inexpensive, standard color pattern. Pushed by this growing use, in the last years several color correction target-based solutions appeared, both commercial and open source, with the aim to minimize the above listed problems.
As reported in [6], the most accurate target-based characterization requires to record its output for all possible lighting and exposure and comparing it with separately measured values for the same lighting and exposure conditions. However, this process generates a massive and unmanageable amount of data. Therefore, the device response is measured only for a selected set of stimuli (e.g. for different CIE illuminant should be done different characterizations, but typically two D series illuminant (daylight) behave in the same way). Starting from this limited set of responses, the transformation between measured CIE*XYZ* values and captured *RGB* values is recovered using one of the techniques among linear transformations, multidimensional lookup tables [7-9], least-squares polynomial regressions [10], advanced regressions [11], neural networks [12] and human-observation-based models [13]. A complete review of these techniques is given in [14].
In many cases, a linear transformation is adequate to map device-dependent and device-independent spaces with adequate performance. Linear approaches are widely

employed for 'color correction' as they preserve two key properties directly related to the camera sensors response to the light sources: scalability and hue planes [15].
Despite above listed benefits, linear correction may produce significant errors [16].
To allow better estimations linear correction was extended with additional polynomials of increasing degree [17]. The polynomial regression method based on least squares fitting has been widely adopted in colorimetric characterization because of its simplicity and good performance [18, 19]. For fixed calibration settings, a polynomial regression can strongly reduce the mapping error [20] allowing significant improvements to color correction.
However, three major problems affect the use of the polynomial regression:

- high degree data expansions can result unstable (rank deficient) [21];
- it is not scale-independent (i.e., data scaled as result of changes in the scene radiance or camera exposure) [22]. This shift can be significant in several cases and this is a significant problem in outdoor captured images;
- the planes of constant hue (i.e. the planes of a matte surface of constant hue parts in light and some in shadow) are not preserved, producing color shifts. Then, for polynomial regression, the colorimetric matrix needs to be recalculated for each exposure change.

Recently some solutions have been proposed for retaining scalability. In the 'Root-Polynomial' regression [23] the n^{th} root of each n^{th} order term in the extended polynomial vector is taken. Tests show that for fixed illumination, root-polynomial based 'color characterization' perform comparably to standard polynomial correction. Nevertheless, in presence of small changes in the scene radiance or exposure it produces significantly better results. In [24] it is demonstrated that, even though 'Root Polynomial' color correction allows to minimize the effect of camera exposure and illumination changes, the technique is sensitive to gradients of scene irradiance. To overcome this drawback, [24] normalizes the *RGB* and *XYZ* vectors prior to performing root-polynomial regression, obtaining a scheme improving max ΔE_{00} but not the mean.
A third solution, basically a variant of the linear approach, are the Adobe Camera Raw (ACR) calibration scripts coming from Bruce Fraser's calibration procedure for successive approximations [25]. This algorithm aims to avoid error due to illumination changes. It exploits a feature on which ACR is originally based to overcome the problem that most cameras respond very differently to tungsten light than to daylight because of their higher sensitivity to red light than to blue, and the makeup of tungsten light, which contains more energy at red wavelengths than at blue ones. Therefore, a single transformation may perform well using the camera's under daylight or tungsten lighting conditions, but probably not under both. To give solution to this problem, for each supported camera, Camera Raw contains two built-in profiles: one related to a tungsten light source, one related to a daylight light source. Camera Raw's White Balance tools - the Temperature and Tint sliders - interpolate between (or even extrapolate beyond) these two built-in profiles.
This accurate solution, however, presents two problems: it is built on Adobe Photoshop and it stopped its development in 2010.
In this paper we present a new ACR-like solution completely written in MATLAB, to be used alone or coupled with a polynomial regression correction, introducing several optimizations and enhancement to the original algorithm. The so-named new SHAFT

(SAT & HUE Adaptive Fine Tuning) differs from the original technique for the number and the types of tests done along the processing pipeline and for the algorithm used to find the best variation from the original values of the selected parameters (exposure, contrast, white balance, hue and saturation on each RGB channel). SHAFT is completely automated exploiting a previously proposed solution for the target recognition on the image [26].

The process is based on the popular target X-Rite ColorChecker Classic (CC) [27] consisting of 24 painted squares with known reflectance applied to paper, then mounted to a cardboard backing with a black frame around all the patches. The CC is currently offered in a 279.4 mm x 215.9 mm size. Patches are organized in a 4 by 6 array, with 18 familiar colors. Six of the patches form a uniform gray lightness scale with optical densities from 0.05 to 1.50; a range of 4.8 f-stops (EV) at a gamma of 2.2 (1 stop equals 0.3 D), and other six are primary colors typical of chemical photographic processes, i.e. red, green, blue, cyan, magenta, and yellow. Remaining colors include approximations of medium light and medium dark human skin, blue sky, the front of a typical leaf, and blue chicory flower. Our CC choice is based on two considerations. At first, its easy availability. Secondly, on the results of studies [28-30] describing methods to select samples from large dataset of surface colors to optimize the colorimetric characterization of camera systems. In these researches the effect of sample selection on characterization performance is evaluated against the standard CC and X-Rite Digital SG ColorChecker charts. Results demonstrates that the original samples of the CC chart appear to have been well selected and it is not easy to find an equivalent number of samples giving substantially better performances.

Finally, tests of the developed new software against previous solutions, in many cases related to the CH and AH, are illustrated.

2. Mathematical definition of the problem

Basically, the problem of ‘color correction’ for digital images stems from the impossibility to represent camera sensor sensitivities as a linear combination of CIE color matching functions, since they violate the Luther-Ives conditions [31]. Surfaces dissimilar to the eye could bring the same camera responses and vice-versa, in a camera-eye metamerism [32]. Color correction is unable to solve this metamerism, but it allows to establish the best possible mapping from camera *RGB*s values to device independent *XYZ*s values (or display sRGBs values [33]).

‘Color characterization’ refers to techniques allowing to convert non-linear camera responses (i.e. RGB), introduced by in-camera processing to enhance the visual quality of captured images, to a device-independent colorimetric representation (i.e. CIE*XYZ*) [34]. The ‘color characterization’ problem is usually solved shaping the non-linear camera response function from observations. In any case, a linear transformation, a 3×3 matrix called the colorimetric matrix, gives an estimated tristimulus value $(\widehat{X_\iota}, \widehat{Y_\iota}, \widehat{Z_\iota})$ from $(R_{i,} G_{i,} B_{i,})$, i.e. assumes that the camera spectral sensitivities are linear combinations of the device-independent ones.

An efficient solution to compute this matrix is to minimize the total visual color difference J, which is a weighted sum of the color differences ΔE (computed e.g. in the CIE perceptual uniform color space Lab) between the target tristimulus $(X_{i,} Y_{i,} Z_{i,})$ and its estimate $(\widehat{X_\iota}, \widehat{Y_\iota}, \widehat{Z_\iota})$, for each patch i, $1 \leq i \leq n$:

$$J = \sum_{i=1}^{n} w_i \Delta E(X_{i,} Y_{i,} Z_{i,} \widehat{X_\iota}, \widehat{Y_\iota}, \widehat{Z_\iota}) \qquad (1)$$

where w_i are the weights for the different patches. The colorimetric matrix is usually obtained through least-squares minimization [35]. Usually the color error parameter is the mean of ΔE_{00}, which is calculated for all patches where $5 \leq L^* \leq 98$ (where L* is defined in CIELAB color space) and each of the R, G, and B channels are less than 99% of the maximum value (i.e., the patch is unsaturated) [36]. In [37], it is noted that the above procedure has the problem that the white point is not preserved, i.e., white in RGB is not mapped to white in the CIEXYZ color space, where white in *XYZ* represents the *XYZ* response to a perfect reflecting diffuser under a specified illuminant; an additional term can be added to *J* to prevent this [38], and more accurate and robust techniques have also been proposed [39].

3. The ACR scripts anatomy

Adobe CameraRaw is a black box not allowing to know the built-in colorimetric matrix, nor the Adobe characterizations set in the used camera database, nor algorithmic image manipulation allowing other changes requested by the user. Despite these secrets, the software ensure accurate colours from raw files basically adapting built-in colorimetric matrix to the behaviour of a specific combination camera/lens, and through specific tools based on some sliders to be handled more or less manually:

- *Shadows Tint,* controlling the green-magenta balance in the shadows;
- *Red, Green, and Blue Hue,* moving the hue angle clockwise or counterclockwise;
- *Red, Green, and Blue Saturation,* allowing to reduce or increase the saturation.

The first to take advantage of this feature to have colour corrected images using a CC was Bruce Fraser that, in his famous article republished more time *Out of Gamut: Calibrating Camera Raw in Photoshop CS* [40-42], described a method to find an accurate placement of colours based on the comparison of the values of the patches of a CC with the Lab values that the CC patches ‘should’ have. The correspondence is obtained by moving carefully the calibration sliders of exposure, contrast, saturation, shadows, in successive approximations. The key is to match the proportions of red, green, and blue in each patch rather than the absolute values.

Later, Thomas Fors automated the Fraser manual process and created his famous ‘ACR Calibrator script’ [43]. Then, starting from the Fors’s one, two authors added their alternative, following new ways and various approaches. These authors are Rags Gardner [24] and Simon Tindemans [44].

All scripts are based on the same procedure: they open many times a raw capture of a CC with several sliders setting and, measuring the result on patches, they search an arrangement giving the smallest error from the reference target value. The basic rule is that the target capture must be evenly lit and properly exposed.

The whole process is divided principally in a phase of basis adjustment and a phase of calibration. In the first phase the script searches an arrangement for white balance and for the patches of the grey row and then, after a further check on white balance, it begins the second phase that is the real calibration process on the colour patches.

For each type of variation, the scripts modify the entity and for each different entity, they evaluate the quality of the results using different error calculation techniques depending on the type of evaluation (e.g. in the hue is used the CIE color metric ΔE_{00}).

Summarizing the three calculation steps are:
- White balance (Temp/Tint)
- Exposure and contrast adjustment (Exp/Blacks/Brightness/Contrast)
- Calibration (Camera Calibration)

The purpose of the first two phases is to minimize the chroma (dC) and lightness (dL) errors of the five gray B4-F4 patches (white patch A4 is particular and not considered). Color Calibration evaluate the color values in all color patches. When adjusting the saturation slider for red it will evaluate all color patches where the dominant channel is red or near red. The same is done for green and blue. The result is usually a compromise calibration across all colors.

4. The proposed solution

Basically, the developed software solution is a RAW image processing implemented in MATLAB and supported by RawTherapee, a cross-platform open source raw image processing program, written in C++, using a GTK+ front-end and a patched version of DCRaw for reading raw files [45]. It allows advanced control over the demosaicing, devignetting, white balance output file in a rendered color space, gamma correction, and 8-bit/16-bit conversion without the need of further software development, exploiting a command-line interface easily coupled with MATLAB [46]. Moreover, it allows avoiding possible 'behind the scenes' as in the Adobe raw converters. In our pipeline only the basic in-camera processing was retained: black point subtraction; bad pixel removal; dark frame, bias subtraction and flat-field correction; green channel equilibrium correction; Bayer interpolation. To avoid uncontrolled modification of the RAW pixel intensity values we did not allow these on-camera processes: denoising; color scaling; image sharpening; color space conversion; gamma correction; format conversion.

The developed software workflow includes three main steps:

a. *RAW image linearization*. The image was linearized to CIE*XYZ* color space and 16-bit encoding to work without missing information exploiting the RAW decoder DCRaw, setting a 16-bit output with fixed white level, gamma equal to 1 and ignoring the image own histogram. It is a well-known that a channel response processing by on-board software is introduced by manufacturers to minimize sensor construction problems, generating non-linearities. However, no further processing to fix these non-linearities than the modifications made by DCRaw were introduced. This solution is not accurate as that in [11], but the final result is very good due to the DCRaw ability to take into account the camera's built-in features.
b. *Exposure equalization and white balance*. First step of color correction consists of a white balance and exposure equalization against a specific patch. White balance was performed with a linear transformation against the patch D4 of the CC. As demonstrated in Viggiano [47] white balancing using an illuminant-dependent characterization produce consistently good results.
c. *Color correction*. SHAFT retain basic idea of the ACR scripts, i.e. to do selective variations and to evaluate the global error ΔE_{00} related to all the patches. SHAFT differs from ACR scripts:
   1) in the number of test carried out;
   2) in the algorithm that is used to find the best variation amount.

In particular, the tests carried out in SHAFT are only of three types:

- exposure variation
- hue variation (selectively on the three channels)
- saturation variation (selectively on the three channels).

To assess the extent of the variation, SHAFT identifies three measurement points over the entire range. Measurements on hue and saturation are evaluated through ΔE_{00}; on the exposure, they are instead evaluated through the luminance difference. Of the three measurements, the two leading to the smallest error are stored, setting new limits for the new search range. The operation is repeated cyclically until the error test (ΔE_{00} *or luminance difference)* continues to decrease. E.g. let's suppose that the initial variation of a test, i.e. the exposure test, ranges from -1 to 1. The three measurement points will initially be set at -1, 0 and +1. Image will be altered exposing it accordingly to the three different measurement points and for each variation, ΔE_{00} will be calculated. The two images leading to the lowest ΔE_{00} will set the new measurement limits. Let's suppose that the best two results in the above case are -1 and 0. These will be set as the new measurement limits, while the new test to be performed will be set at their half: 0.5. This process will cycle recoursively, until a ΔE_{00} improvement is measured. In most cases, the best ΔE_{00} results are recorded at contiguous measurement points, i.e. -1 and 0 or 0 and +1. In a few cases, the lowest errors are recorded at measurement limits, i.e. -1 and +1. This could mean that the amount of error is not linearly correlated to the amount of variation and a larger amount of samples across the variation range could be necessary. In the case above, where the initial measurement points were set at -1 0 and +1 and the best ΔE_{00} recorded at -1 and +1, the new samples number will be increased by one and set at -1 -0.33, +0.33, +1. The process is summarized in the scheme of Figure 1.
Hue and saturation variations are performed selectively for the three RGB channels as six different tests (Red, Green, Blue Hue; Red, Green, Blue Saturation). In particular, hue and saturation ranges are subdivided in three parts, each one corresponding to one channel (Figure 2). The entity of change is maximum (v=1) within the degrees corresponding to the channel (R:300-60°, G:60-180°, B:180-300°) and minimum (v=0) within the degrees not corresponding to the channel (R:120-240°, G:240-360°).

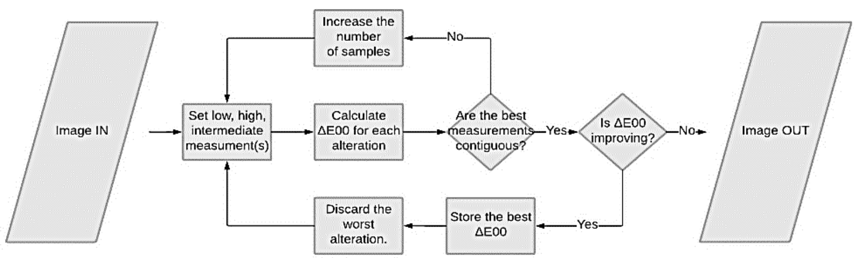

Fig. 1 - SHAFT process flow

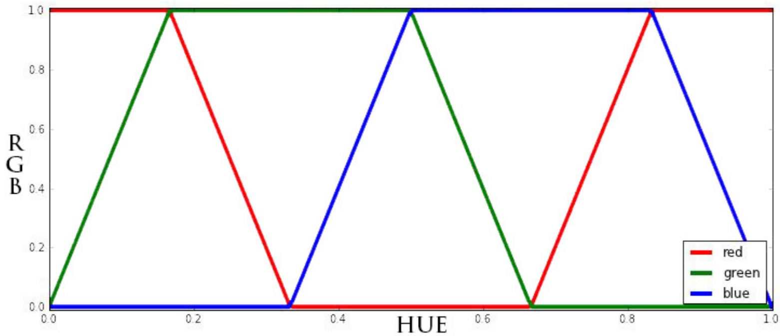

Fig. 2 - X axis: Hue degrees normalized to 1 (360°=1). Y axis: RGB multiplyer.

This 'color characterization' technique is combined with the CIE color metric [48]:

$$\Delta E_{00} = \sqrt{\left(\frac{\Delta L'}{k_L S_L}\right)^2 + \left(\frac{\Delta C'}{k_C S_C}\right)^2 + \left(\frac{\Delta H'}{k_H S_H}\right)^2 + R_\tau \frac{\Delta C'}{k_C S_C}\frac{\Delta H'}{k_H S_H}} \qquad (2)$$

which is given by the CIE in 2000 recommended by CIE mainly for color differences within the range 0-5 CIELAB units [49, 50]. 8-bit sRGB by Denny Pascale [51] have been used as reference for CC built before November 2014 and measurements with a spectrophotometer for CC built after November 2014.

An important consideration is the use of Gamma corrected color spaces. While 'Gamma correction' was originally intended to compensate the non-linear response of the CRT monitor, by a remarkable coincidence the non-linear response of the human visual system is approximately the inverse of the nonlinear response of a CRT monitor. Thus, gamma pre-corrected color signals are already approximately perceptually coded. Technically speaking in the 'Gamma Correction' model, the input is linear brightness, with values from 0 (black) to 1 (full brightness) and is applied over each *RGB* color component. The output is the 'Gamma corrected' (non-linear) brightness. The 'Gamma correction' function for digital cameras, is as follows per channel:

$$new\_val = \left(\frac{old\_val}{max\ \_val}\right)^{y} \cdot max\_val \qquad (3)$$

where *max_val* is the maximum allowed value (i.e. 255 for 8 bit-depth representation).

In our workflow, before color balance, considering that the linear brightness is not perceptually linear, a 'Gamma correction' is applied. The value $\gamma = 2.2$ is used, well-fitting the behavior of the output color space sRGB. This operation converts all images into the camera's native linear color space, refining their quality.

In the 'color correction' process, a key-point is the use of appropriate color spaces in which to apply the color correction algorithms given above and the scene-referred non-linear color space for the output images [52]. The processing color space used is the CIEXYZ taking in account the consideration that using this color space, errors calculated by the least squares fitting algorithms allows to produce final corrected images that look more closely matched to the original image [53]. Our final color space is the rendered space sRGB, the today IEC 61966-2-1 default color space for multimedia and 3D graphics application [54], allowing consistent color reproduction across different media despite its color gamut is narrower than the human one and does not allow to display properly saturated colors such as yellow cadmium and blue cobalt.

5. Evaluation and tests cases

For the evaluation of the performances, the implemented solution was tested in different contexts: photo studio, indoor, architectural scenarios and outdoor environment where natural light characteristics are extremely complex and changeable.
A dataset of RAW camera images consisting of 22 images representing different cases and problems and including the CC chart was selected (Figure 3).
Images comes from different cameras and lenses ranging from an ultrahigh resolution scanback Rencay [55] to a smartphone camera. In detail, we used:

A. *Rencay superfineart* scanback (three CCD linear sensor Kodak KLI-8023: 8002 pixels per line, resolution: 8934 x 6398 pixels, 48 bit-depth) on a Linhof Master Technika classic 4x5", Schneider Kreuznach Digitar Apo 180mm f 5,6 lens;
B. *Nikon D200* SLR camera (CCD sensor 23.6x15.8 mm, resolution: 3872x2592 pixels, 36 bit-depth), Nikkor 18-135mm zoom lens, focal length used: 18 mm;
C. *Nikon D3100* SLR camera (CMOS sensor 23.1x15.4 mm, resolution: 4608x3072 pixels, 42 bit-depth), Nikkor 18-55mm zoom lens, focal length used: 18 mm;
D. *Nikon D5300* SLR camera (CMOS sensor 23.5x15.6 mm, resolution: 6000x4000 pixels, 42 bit-depth), Nikkor 18-55mm zoom lens, focal length used: 35 mm;
E. *Canon EOS 5D Mark III* SLR camera (CMOS sensor 36.0x24.0 mm, resolution: 5760x3840 pixels, 42 bit-depth), Canon EF 24-105mm zoom lens, focal length used: 35 mm;
F. *Canon EOS 600D* SLR camera (CMOS sensor 14.9 x 22.3 mm, resolution: 5184x 3456 pixels, 42 bit-depth), Canon 18-55mm zoom lens, focal length used: 18 mm;
G. *Apple Iphone 7plus*: primary camera 12 MP 1/3-inch sensor, with f/1.8 aperture, 28mm-equivalent focal length; secondary camera 12 MP 1/3.6-inch sensor, with f/2.8 aperture and 56mm-equivalent focal length.

The developed software is compared on the 22 images to:

- Manual 'color correction' based on DXO Optics Pro 10;
- X-Rite ColorChecker Passport Camera Calibration Software [56];
- Adobe Camera Raw (ACR) calibration scripts in the implementation of [24];
- A previously developed solution based on polynomial regression [26];
- A linear transformation as implemented in Imatest 4.5 [36].

The evaluation of color accuracy, based on a CC target, comprises: a physical reference chart acquired under the current illumination (corresponding to the illumination to be discard); a reference chart color space with the ideal data values for the chart; a way to relate or convert the device color space to the reference chart color space; and a way to measure and show errors in the rendering of the reference chart.
Color accuracy was computed in terms of the mean camera chroma relative to the mean ideal chroma in the CIE color metric (ΔE_{00}) as defined in 2000 by the CIE on the CIE*XYZ* chromaticity diagram. The ΔE_{00} calculation was made using the ColorChecker tool of Imatest Master software version 4.5 [36]. As previously, reference values also here were used the 8-bit sRGB by Denny Pascale [51] for CC built before November 2014 and measurements with a spectrophotometer for CC built after November 2014. Exposure error in f-stops was also evaluated.

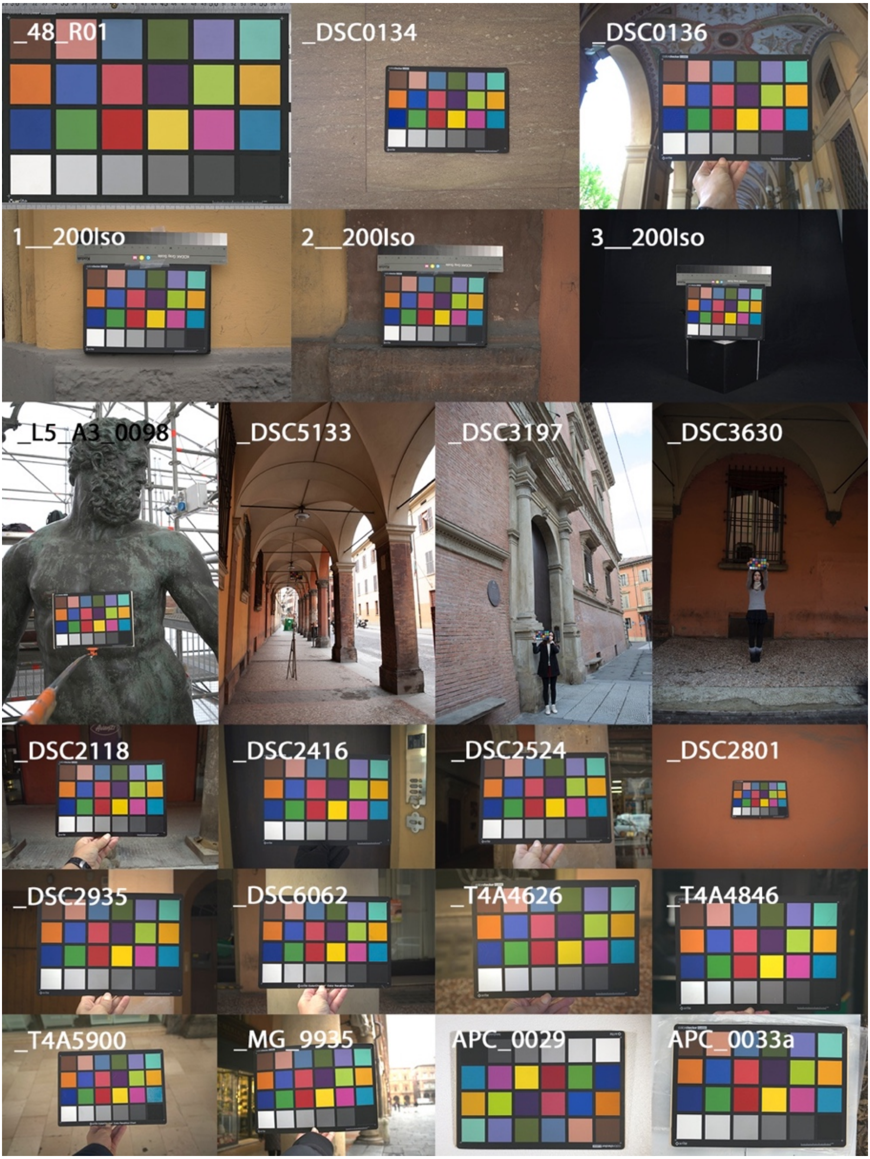

Fig. 3 - Dataset of 22 RAW images with CC evaluated.

6. Results and conclusions

Results are shown in Table 1 and Table 2, demonstrating that the SHAFT solution outperforms the other algorithms in general and in the most specific conditions. Also, the good results of the Imatest linear solution are expected because the software presents a manual fine-tuning recognition of the target, a customizable algorithm depending on the camera type and the context in which the target is placed and its illuminant and illumination conditions.

Camera Type	File Name	ΔE*$_{00}$					
		Manual	X-Rite Passport	ACR	Polynomial	Imatest	SHAFT
Rencay	_48_R01	3.66	NA	3.16	3.88	4.22	**3.12**
Nikon D200	_DSC0134	3.49	10.6	3.54	2.28	**1.73**	2.15
	_DSC0136	3.81	24.0	4.89	2.84	**2.28**	2.51
Nikon D5300	_L5_A3_0098	7.93	12.5	5.36	4.24	6.02	**3.68**
	1__200Iso	4.27	7.76	3.14	1.86	6.71	**1.38**
	2__200Iso	4.36	6.89	3.41	2.08	7.13	**1.65**
	3__200Iso	4.47	5.52	3.89	2.65	6.87	**1.99**
Nikon D70	_DSC5133	3.46	30.6	4.22	6.53	3.64	**3.61**
Nikon D3100	_DSC2118	3.84	7.54	3.35	1.75	**1.76**	**1.72**
	_DSC2416	3.58	8.24	3.93	2.59	2.39	**2.38**
	_DSC2524	3.59	4.87	3.07	1.54	**1.42**	**1.42**
	_DSC2801	3.57	6.28	3.32	1.85	**1.73**	**1.70**
	_DSC2935	3.81	6.36	3.27	2.80	**2.32**	2.70
	_DSC3197	3.55	8.94	3.84	5.63	**1.79**	3.06
	_DSC3630	3.23	9.87	2.84	5.84	**1.72**	3.03
	_DSC6062	3.53	8.67	3.20	1.87	**1.81**	**1.80**
Canon EOS 5D Mark III	_T4A4626	7.23	7.12	8.40	5.46	4.91	**4.81**
	_T4A4846	3.95	8.63	**3.12**	4.21	3.86	4.04
	_T4A5900	3.87	5.73	4.23	2.26	**1.55**	2.05
Canon EOS600D	_MG_9935	4.27	17.1	4.75	2.92	**1.84**	2.71
Apple Iphone 7S	APC_0029	2.11	19.1	**3.11**	4.15	6.43	3.79
	APC_0033a	4.33	11.6	4.4	4.07	5.04	**3.57**
Mean error		**4.09**	**10.85**	**3.93**	**3.33**	**3.44**	**2.68**
Standard deviation		**1.24**	**6.62**	**1.21**	**1.50**	**2.08**	**0.95**

Tab. 1 – ΔE*$_{00}$ evaluation

Camera Type	File Name	Exposure error (f-stops)					
		Manual	X-Rite Passport	ACR	Polynomial	Imatest	SHAFT
Rencay	_48_R01	0.19	NA	0.03	-0.02	0.06	-0.02
Nikon D200	_DSC0134	0.09	-0.24	0.01	0.01	0.06	0.01
	_DSC0136	0.01	-1.53	-0.05	0.00	0.02	0.01
Nikon D5300	_L5_A3_0098	0.09	0.28	-0.03	-0.01	-0.07	-0.01
	1__200Iso	0.09	-0.13	-0.00	0.01	-0.00	0.01
	2__200Iso	0.11	-0.06	-0.03	0.01	0.07	0.01
	3__200Iso	0.09	0.17	-0.00	-0.00	0.03	-0.00
Nikon D70	_DSC5133	0.06	-1.86	0.05	-0.10	0.03	-0.10
Nikon D3100	_DSC2118	0.05	0.27	0.02	0.02	0.00	0.02
	_DSC2416	0.05	-0.46	-0.04	0.02	0.11	0.02
	_DSC2524	0.05	0.12	0.03	0.02	0.07	0.02
	_DSC2801	0.07	0.22	0.04	0.02	0.12	0.01
	_DSC2935	0.09	0.14	0.06	0.04	0.15	0.04
	_DSC3197	0.04	-0.39	0.03	-0.04	0.02	-0.04
	_DSC3630	0.10	-0.57	0.03	-0.04	0.06	-0.04
	_DSC6062	0.01	-0.40	-0.13	-0.02	0.04	-0.02
Canon EOS 5D Mark III	_T4A4626	0.08	-0.55	0.02	-0.06	-0.18	-0.06

	_T4A4846	0.06	0.30	-0.04	-0.01	-0.00	-0.01
	_T4A5900	0.06	-0.31	0.03	-0.01	-0.03	-0.01
Canon EOS600D	_MG_9935	0.24	-1.09	0.08	-0.00	-0.03	-0.00
Apple Iphone 7S	APC_0029	0.06	-1.27	-0.03	0.00	0.10	-0.00
	APC_0033a	0.18	-0.87	0.05	0.01	0.09	0.01
Mean error		**0.09**	**-0.39**	**0.00**	**-0.01**	**0.03**	**-0.01**
Standard deviation		**0.05**	**0.62**	**0.05**	**0.03**	**0.07**	**0.03**

Tab. 2 – Exposure error in f-stops evaluation

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Is it possible to apply colour management technics in Virtual Reality devices?

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1. Introduction

Virtual Reality (VR) has witnessed a great development during last years. The improvement of Head Mounted Displays (HMD) allows visual immersive experiences in virtual environments and will have many applications, in both recreational and professional fields [1] [2]. The quality of these immersive experiences is a key factor and depends on the capability to generate the feeling of presence over a distance [3].

The feeling of telepresence starts with the perception of depth, which is visually achieved by generating two different views of the same scene. Each of them must be generated with a different point of view that differs by a distance equivalent to that existing between the pupils of humans and a proper eye alignment. This generates the effect of stereoscopic vision or three-dimensional perception, which provides the observer the depth perception of a scene. In addition, the visual system of the observers must have complete functionality (simultaneous perception, fusion and stereopsis). However, differences in depth and camera distances have significant impacts on depth perception [4].

Showing a stereoscopic image is not enough to obtain a good telepresence feeling. This stereoscopic image must have several visual properties. For example, it is necessary to have a wide field of view, larger than the field of view shown on a film or television screen [5] [6]. While the human being has a visual field of about 200°, the stereoscopic vision can only provide about 110° [7]. From a technical point of view, the large field of vision in a HMD is achieved by placing the screen very close to the observer eyes; this forces to introduce lenses that allow to accommodate the eye on the screen at a short distance in all VR HMD devices. These lenses, in turn, can deform the visual field, due to the optical aberrations introduced by themselves, and can also cause the perception of light dots on the screen (image pixelation) [8].

In addition, in order to produce a good feeling of telepresence, the VR device must be able to detect the movements of the head and generate different views of the same scene with sufficient speed and very little delay. This concept is known as low latency [9] [10].

The VR imaging system must be able to generate images at a rate enough to detect no flicker and, moreover, to change the image generated according to the movements performed by the observer's head as quickly as possible (at least between 90 and 120 Hz). To achieve this, it is necessary to have some hardware and software elements that can track the movements and render the images with sufficient speed. These hardware elements are gyroscopes, accelerometers and positioning cameras that, by simple calculations, allow to know the exact position of the head of the person who uses the VR device. All this results in an improved telepresence perception and a better quality of the virtual reality experience.

In a previous work, the authors have stated that the colour is the most significant factor influencing the quality of the virtual reality experience in terms of generation of the virtual image in relation to the original one [11]. In consequence, the improvement of the fidelity in the chromatic reproduction can be considered as a suitable further step towards the evolution of the quality of the systems of virtual reality.
The chromatic characterization of electronic devices is essential in order to accomplish the improvement of the chromatic reproduction of digital images; in this way, the univocal relation between digital and colorimetric values has to be known. This mathematical relation can vary depending on the type of device and has to be studied for each different type of technology (CRT, TFT, OLED, …) [12] [13] [14]. Once the mathematical relation between *digital colour* and *colour independent from the device* is known, a system for colour management has to be implemented and the colorimetric ICC profiles associated to each device have to be used.
The colour management system sets up a series of colorimetric transformations that allows to transform the coordinates of the colours spaces independent of the device (CIE XYZ, CIE Lab) to those of the colours spaces device-dependent (RGB, CMYK) and vice versa. All these mathematical transformations require a computation time that is often too long, since the resolution and refresh frequency values of the device are such that the colour management becomes inviable from the technical point of view, because the linking of several colorimetric transformations is needed.
Therefore, it is time to wonder whether it is possible to make a correct colour management in VR devices as it was done in other digital environments through the colour characterization of colour reproduction devices (Displays, printers, etc.) and the use of ICC colorimetric profiles. In this work, we face this issue in a first approach, propose a solution and show the obtained results.

2. Methodology

In recent years, different commercial devices oriented to virtual reality have been developed by different companies such as Google, Oculus, and HTC. In all cases, the VR imaging system is able to generate images at a high enough rate (at least between 90 and 120 Hz). In this work, we have employed the latest commercial version of the Oculus Rift virtual reality glasses (CV1). This HMD is equipped with two custom displays, one per lens, manufactured by Samsung Display Co. These displays are AMOLED type with a native resolution of 1200 x 1080 pixels, 3.51" of diagonal size and a resulting pixel density of 456 ppi.
The difference between calibration and colorimetric characterization of a colour display device is always confusing. Calibration of one of these devices consists in setting its state to a known value. This could be done by fixing the white point, the gain, and the offset for a cathode ray tube, for example. It ensures that the device produces consistent results, and the calibration process can be completed without any information on the relationship between the device’s input coordinates and the colorimetric coordinates of the output. The colorimetric characterization of the device, however, requires this relationship to be known: characterization is obtaining the relationship between the device’s input coordinates and other device-independent coordinates. Due to the large number of chromatic stimulus that can be shown by any

digital device, the direct measurement of this relation is impossible, and therefore a mathematical model is applied, enabling to reduce the number of runs.
We have chosen a display characterization model that does not require the actual operation of the display to be followed, but only seeks to relate as simply and accurately as possible the values of the DAC with the chromatic values of the stimulus in any reference colour space. We have chosen the classical linear model using a previous non-linear gamma correction.
The chromatic characterization of the Oculus Rift was performed by making some previous studies, which allowed to generate the chromatic stimulus needed. These works are mainly related to the software that allows to use this device.
Oculus Rift is provided with a Software Developer Kit (SDK) that includes a simple predefined project for Visual Studio with several graphics libraries as DirectX11, DirectX12 and OpenGL. Specifically, we have defined a 3D scene in that project using OpenGL. In this scene, we have displayed an image with an embedded ICC profile which allows us to easily check if the colour management is performed by the system.

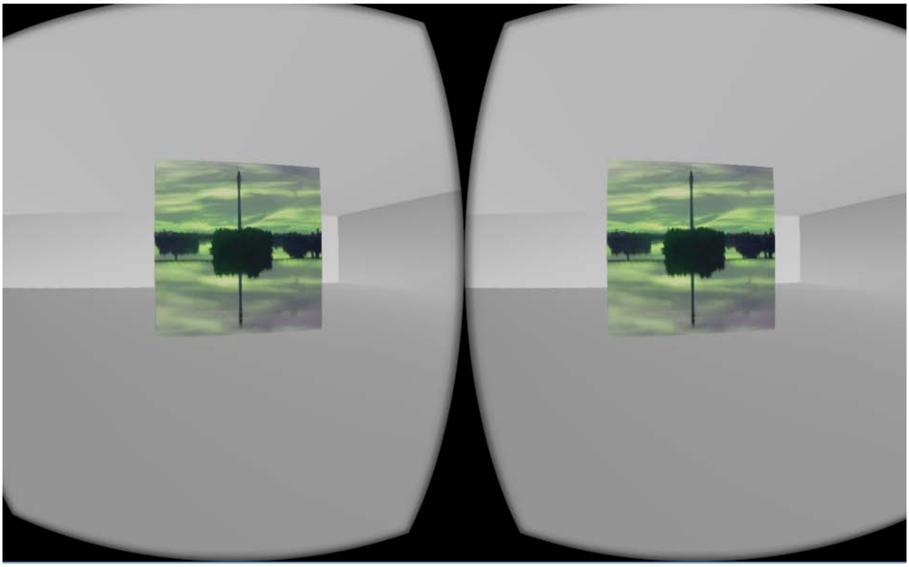

Fig. 1 – JPEG image with embed ICC profile shown in a virtual room for checking colour management.

This image has altered the chromaticity coordinates of red and green channel in such a way that if the image is shown in red/orange tone, the system manages the colour in the correct way. On the other hand, if the appearance is greenish the colour management is wrong. In this case, it has been verified that no type of colour management is performed by default.
In the same 3D scene, we have defined a uniform colour cube whose colour can be changed freely using RGB coordinates. We have made the chromatic characterization of the HMD by changing the cube's colour and measuring the spectral radiance of the HMD through its lens.

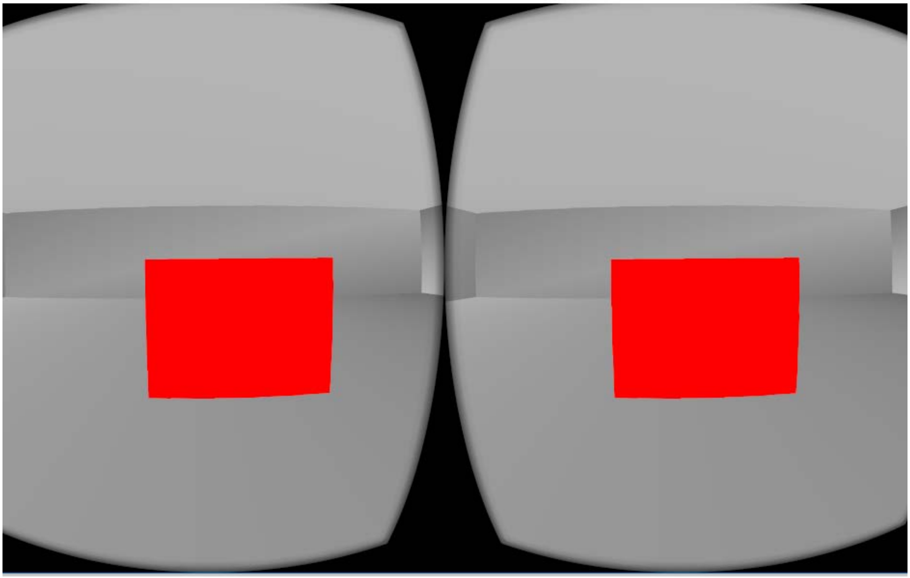

Fig. 2 – Colour cube shown in a virtual room for radiometric measurements while colour is changed.

We have modified the original project called *Oculus Room Tiny* in OpenGL version for Visual Studio 2015 provided by the Oculus SDK. Using the initial room as starting point, we have removed all the objects and have created a new cube-shaped geometrical figure where the colour changes have been applied. This cube has been implemented by using the method *AddSolidColourBox* modifying the constructor parameters in order to locate it in the target site.

Once the cube has been built, we have implemented a method that allows changing the cube colour as a function of the RGB values introduced, and, later on, we have made the spectroradiometric measurements needed for a correct chromatic characterization.

The measurement instrument employed was a Konica-Minolta CS-2000 tele-spectroradiometer with a spectral resolution of 1 nm between 380 and 780 nm, a <2% radiance measurement error and CIE 1931 x = ± 0.0015; y = ± 0.0010 colour error for an illuminant A simulator.

Fig. 3 – Experimental setup used for chromatic characterization of Oculus Rift Device.

3. Results

The chromatic characterization of the Oculus Rift virtual reality glasses has been made using the experimental set up shown in figure 3 and has allowed obtaining the following conclusions.

3.1. Spectral Power Distribution

The spectral power distribution of the white point was measured using the setup shown in fig. 4. The spectral radiance of each channel reveals the OLED nature of this display with a narrow bandwidth for each primary RGB.

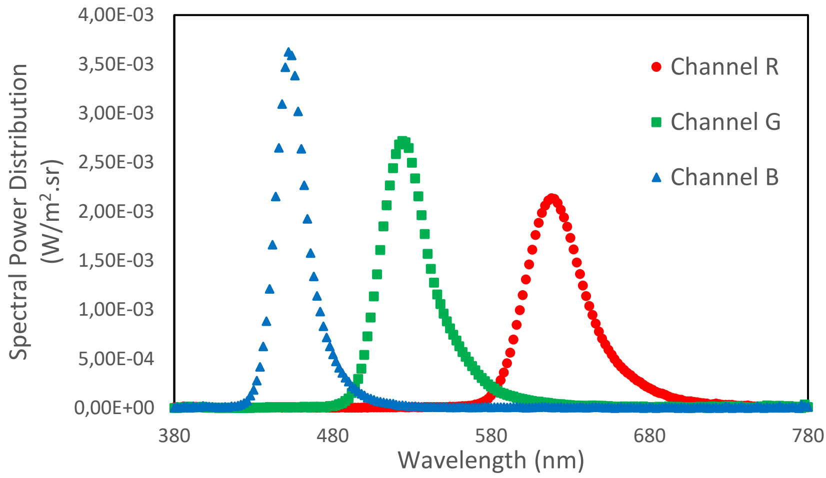

Fig. 4 – Spectral power distribution of RGB channels at maximum DAC value.

Table 1 shows the chromaticity and luminance of each independent channel and the media white point.

	x	Y	Y (Cd/m²)
White	0,306	0,322	75,1
R	0,664	0,332	22,4
G	0,227	0,712	58,2
B	0,146	0,041	4,5

Tab. 1 – Chromaticity coordinates and luminance of channel RGB at maximum DAC value and media white.

3.2. Colour gamut

The colour gamut is a subset of colours which can be accurately represented in a given colour space or by a certain output device like a display. We have measured the colour gamut of our oculus rift device showing a wider gamut than other display types.

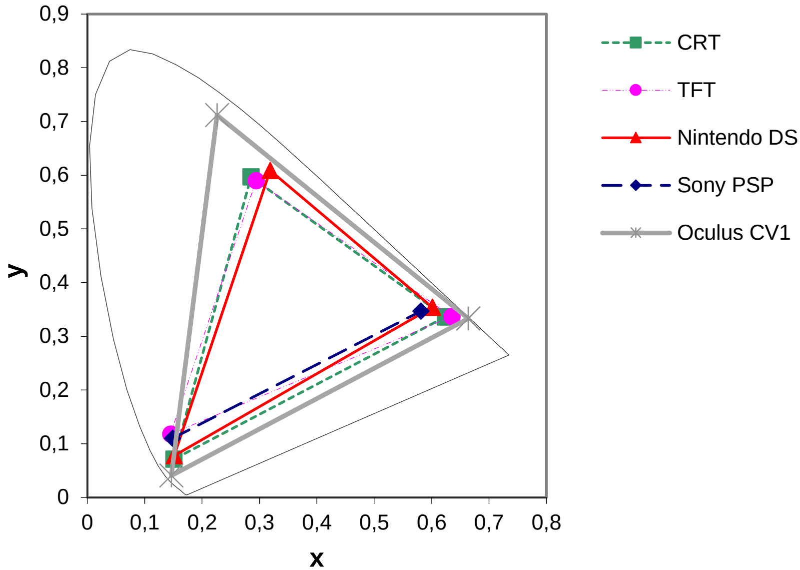

Fig. 5 – Colour gamut of Oculus Rift display compared with colour gamut of different types of displays.

3.3. Relation between Device Dependent and Device Independent colour coordinates

We have measured the relation between device dependent RGB colour coordinate and device independent XYZ tristimulus coordinate for each colour channel independently. This relation is shown in figure 6. By analysing the subjacent mathematical model using a non-linear fit we have obtain three gamma values, one for each RGB channel. The R-squared coefficient of each mathematical fit is close to 1.

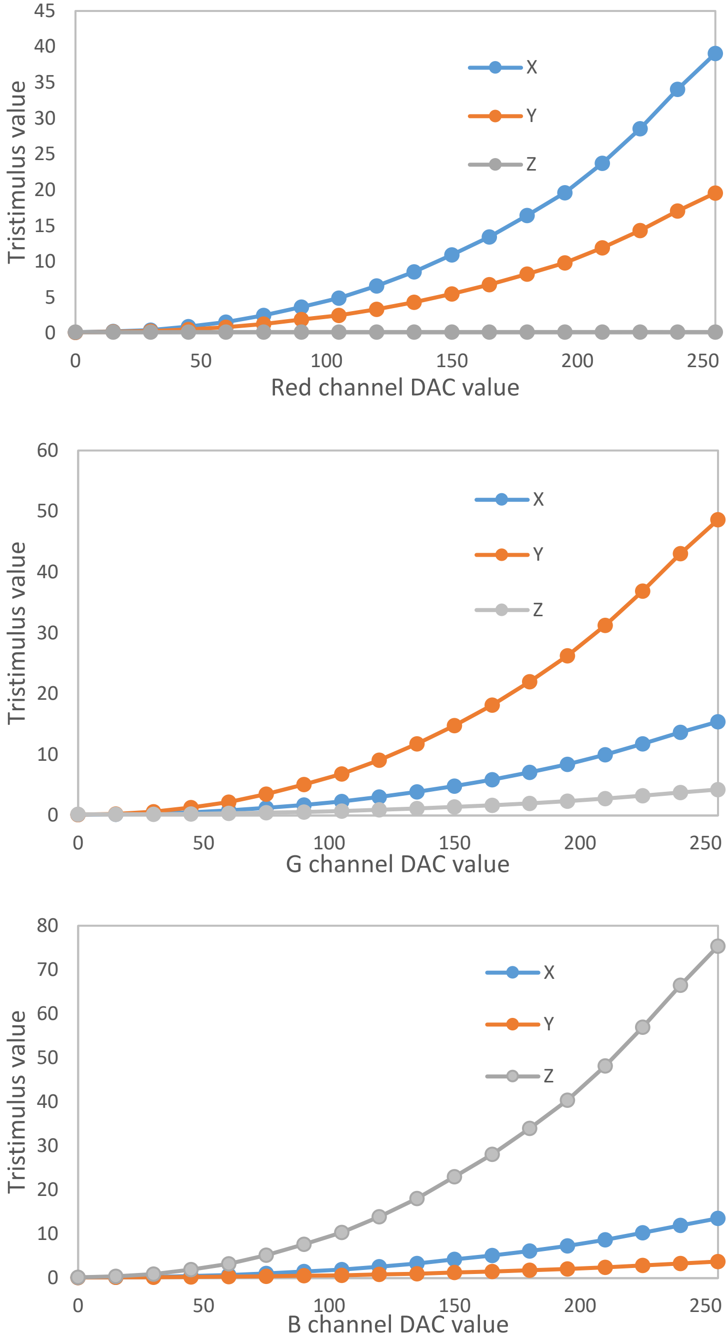

Fig. 6 – Relation between DAC and tristimulus values for each RGB independent channel.

In order to confirm the goodness of the chromatic characterization made, 30 RGB colour measurements, generated at random, were made. These values were compared to those forecasted by the mathematical model, obtaining an average colour difference of ΔE_{00}=1.72.

3.4. Colour management system

Using the previous colorimetric characterization data, we have defined a custom ICC colour profile for our Oculus Rift device. We have developed a simple library that allows us to define a colour in CIE XYZ and CIE Lab coordinates and transform it to the default RGB coordinates of the system. In this way, it is possible to apply colour management transformations to colour images in VR devices and obtain a better colour fidelity reproduction. We have checked this library with our test image obtaining a fine colour reproduction of it.

4. Conclusions

Virtual Reality devices need a very high image refresh frequency and a very high screen resolution for a good immersive experience. These requirements make difficult to apply a correct colour management to digital images. We have made the chromatic characterization of this device and have defined a colour transform library and an ICC colour profile. In this way, it is possible to apply colour management transformations to colour images in VR devices and obtain a better colour fidelity reproduction.

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Study on angular effects correction of 3D laser scanner optical signals for accurate colour estimation and digitalisation

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1. Introduction

In the modern digital era, 3D representation appears to be the most successful innovation in many application fields, from gaming up to Cultural Heritage (CH). A challenging and complex aspect of artworks three-dimensional digital transposition is the colour accuracy, fundamental for the fruition and comprehension of the artefact itself but also for its conservation and restoration. Nowadays, there are many technologies for the 3D survey and modelling, most of which acquires colour information using cameras involving problems related to ambient illumination, uniform white balancing and limited depth of focus [1]. The prototypal system used in this study is the RGB-ITR laser scanner (Red Green Blue-Imaging Topological Radar), developed by Diagnostics and Metrology Laboratory at the ENEA Research Centre in Frascati (Rome, Italy), which allows the 3D colour digitalization of artworks even at great distances without any ambient light influence or need of scaffolding, exploiting the interaction between laser light and surface materials. This paper presents a correction study carried out on RGB-ITR optical data with the aims to delineate a complete calibration procedure able to balance distance and angular effects and, at the same time, reduce timing spent for *in situ* calibration applying the procedure in post-processing operations. The technology behind this scanner makes it a competitive tool in CH field for the 3D reproduction of artefacts, allowing remote and non-invasive colour and structural monitoring. At the moment, the system uses three wavelengths in the visible range and, through the phase-shift estimation and the back-reflected signals intensity analysis, it is able to obtain both distance and colour information of the scanned object. As of now, RGB-ITR optical signals correction includes only a linear calibration for white balancing along all the distances range but many studies [2-4] proved the effects of incidence angle on data quality, requiring the necessity of an appropriate calibration procedure in order to achieve colour accurate
3D models and reduce optical distortions. Through laboratory tests and the analysis of the optical signals trend, this work introduces an angular colour correction for the calibration of laser data. The formulated procedure has been applied on the 3D digitalization of the Saint Brizio Chapel in the Orvieto Cathedral (Terni, Italy). The paintings inside the Chapel, also called *Cappella Nova*, are one of the first representations of the Last Judgment dated back to 1502 by Luca Signorelli, considered the Renaissance reference, even by Michelangelo Buonarroti [12][13]. The
3D digitalization and the accurate colour transposition of this artistic, stylistic and historical proof of the Italian Early Renaissance has an important role for conservative purposes and for the transmission to the future generations.

2. Colour information from back reflected signals

The colour attribute of the 3D models achieved with the RGB-ITR system is estimated by the detection of the three back reflected opto-electronic signals, expressed in Volts, from the target. This physical quantities are function of the wavelengths (λ), the distance (x) and the angle formed between incidence laser beam direction and the surface normal (θ_i). The normalised reflectance is defined as the ratio between the opto-electronic signals acquired from a point on the scanned surface and the calibrated white target, placed perpendicularly and at the same distance from the ITR sensor:

$$R = \frac{V(\lambda, x, \theta_j)}{V(\lambda, x, \theta_j = 0)} \tag{1}$$

Before this work, the RGB-ITR data were calibrated using distance information, namely applying the amplitude values of the RGB curves at selected distances without considering the incidence angle effects. This study introduces the angular correction factor based on the Lambert's law that describes an ideal diffuser as reflecting with an intensity ($_e$) proportional with the cosine of the angle θ formed between the laser incidence direction and the surface normal (Fig.3) [8]:

$$I_e = I_e(\theta = 0) cos\theta \tag{2}$$

In the particular case of RGB-ITR scanner, Eq. (2) can be express as:

$$V_0 = V_0(\theta = 0) \cos\theta \tag{2.1}$$

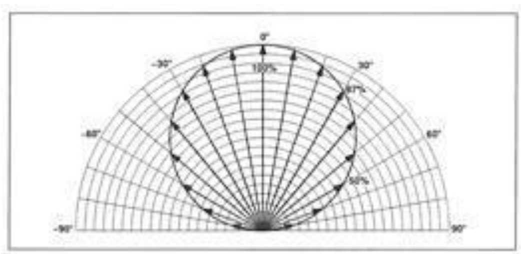


Fig. 3 – Representation of the radiant intensity diffuses from a Lambertian surface as function of angle .

3. Laboratory acquisitions: instruments and procedure

This paragraph describes the experimental setup and procedure used for studying laser optical signals behaviour at long distances and different angular ranges. The laboratory tests were performed in a hangar and illuminating by the three laser sources a certificated Lambertian white target (Spectralon STR-99-020). The white target was placed on a 3D printed rotating structure, equipped with a goniometer for an easily angular positioning and reading, and mounted on a tripod. The hangar floor was labelled every 1m along a linear range up to 29m from the centre of the ITR scanning mirror, for an easily and rigorous positioning of the tripod. Data collection and processing were used for developing a calibration procedure applied to real cases, like the 3D digitalization of the Saint Brizio Chapel.

3.1 RGB-ITR scanner

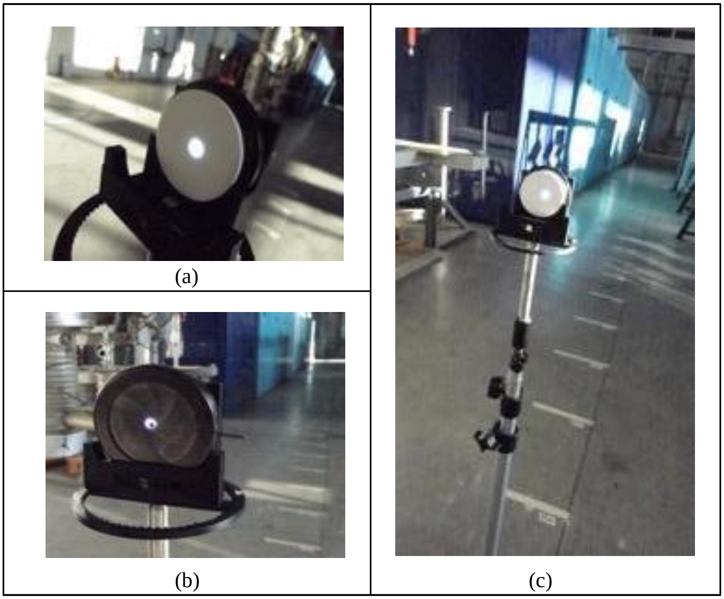
The ENEA laser scanner prototype is a multi-wavelengths system for the remote colour digitalization of surfaces up to 35 meters-distance. The RGB-ITR system is composed by two principal modules connected each other by optical fibres: the optical head, equipped with a scanning mirror which points the laser beam on the surface; the electronics components for the generation, modulation and acquisition of optical signals (Fig.1). This laser scanner employs three amplitude-modulated [5] laser sources (660 nm, 517 nm and 440 nm) which are superimposed on a single spot by the use of a dichroic filter. The back reflected photons from the surface are collected by three different photodiodes, which convert the optical signals in electronic ones. At the end of this chain three lock-in amplifier instruments estimate the reflectance by the signals amplitude and the distance by the phase-shift between reference and reflected modulating sinusoid from the investigated scene.

Fig. 1 – RGB-ITR laser scanner inside the laboratory: the electronics components in the tower configuration and the optical head set on a tripod.

RGB-ITR scanner is driven by a software called *ScanSystem,* which allows to set acquisition parameters, plan the digitalization process and store the collected data. The *itrAnalyzer* software is designated to post-processing data analysis, mesh creation, structure and colour surfaces inspection. Actually the ITR scanners have fixed launching and receiving focal lenses: in this experiment the lasers spot was optimised at a distance of 10m, while the receiving optical system was optimised at a distance of 6.5m. More details about the RGB-ITR system and software are described in [3][6][7].

3.2 Laboratory setup and data acquisition

The laboratory tests have been carried out in a hangar chosen for the available wide space, in line with the aims of this work: study of the optical signal behaviour at great distances and delineation of a complete calibration method applicable even to long distance and wide angular ranges. The reflectance data have been achieved from the white target with 1 meter-step from 3 to 29 meters of distance from the RGB-ITR mirror, following the labels put on the hangar floor. The white reference has been placed on a calibration system composed by a 3D printed structure properly designed for a rigorous angular rotation of the target and assembled on a tripod for an easy movement along the distance path. The 3D-printed structure is composed by a case with two slots for the vertical housing of a calibrated white target (Fig. 2a) and a diaphragm (Fig. 2b), placed one in front to the other; this support is also equipped with a goniometer, which centre is aligned with the calibrated target vertical axis passing for its centre, for an easy placement and reading of the target angular rotation (Fig.2c).



(a) (b) (c)

Fig. 2 -Laboratory setup: a) reference target on its slot; b) particular of laser beam collimation through the diaphragm set on the second slot; c) calibration system on the tripod inside the laboratory.

For this work the white calibrated target was before translated to a labelled position long the linear range in the hangar and then rotated around the vertical axes, passing for the target centre, in a range between -70 and 70 degrees with a step of 10 degrees. Before each distance step, a diaphragm has been placed in front of the target in order to centre the laser beam on the target centre, then removed and started the acquisitions rotating the case at fixed positioning inside the angular range. Calibration data has been recorded with the specific panel of *ScanSystem* software. Launching and receiving optics have worked on generalized operating conditions, reproducing the average of distance between the scanning system and real possible scenarios. Table 1 summarises both laboratory and instruments parameters for performing the described experiment.

Distance system-target	Angular range	Spot focalization	Receiving maximum	Num. measures per point	Double amplitude modulation	Acquisition velocity
3 ÷ 29 meters	-70° ÷ 70°	10 meters	Fixed at 6 meters	20	Low freq.: 5 MHz High freq.: 190 MHz	Fixed at 1kHz

Tab. 1 – RGB-ITR working parameters during laboratory acquisitions.

The Lambert's law describes the dependence of the back-reflected light with the incidence angle: the highest values of reflectance are obtained when the laser beam irradiates perpendicularly the scanned surface ($\theta = 0° \rightarrow \theta = 1$); viceversa, the lowest are acquired when the incidence angle is $\theta = 90° \rightarrow \theta = 0$.
The introduction of the correction expressed in Eq. (1) allows to compensate just the Lambertian component of the back reflected signals collected by the ITR scanner, reducing the signals loss caused by the angular effect between the incidence lasers vector path and the surface normal.

4 Data analysis and Results

Post-processing data manipulation has been carried out dividing the elaboration into two steps: (i) analysis of the signals and (ii) formulation of the correction method. For the first phase the behaviour of optical signals has been studied, analysing the trends in comparison with distance and angular ranges (Fig4.). The best performance has been observed with a small incidence angles: higher values of reflectance have been achieved within -20° and 20° angular range from 5 up to 15 meters of distance.

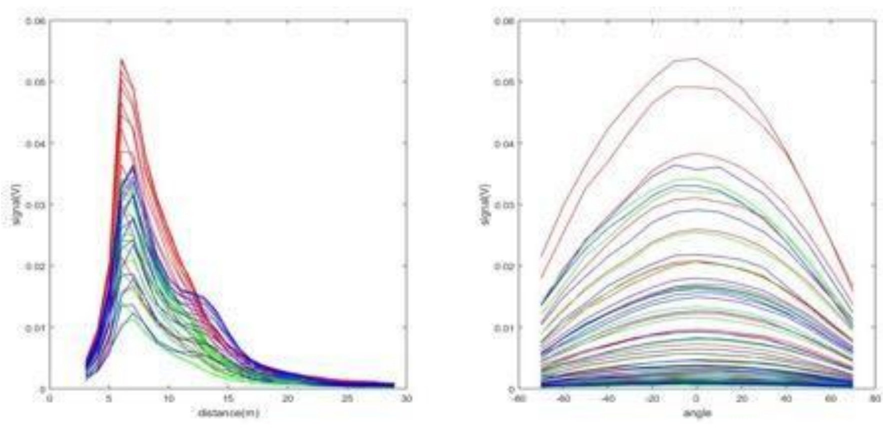


Figure 4. RGB-ITR data: signals trend as a function of distance(left) and angles(right).

In order to relate RGB-ITR optical signals to the *Lambert cosine law*, the following equation has been applied to the laboratory dataset:

$$y = a \cdot \cos\theta \qquad (3)$$

Where a represents the voltages acquired with θ= 0 at the distance range.
Fig. 5 shows the comparison between laboratory data and cosine law reference curves. As the figure shows, the two trends are comparable, even if perfect matching is not always found.

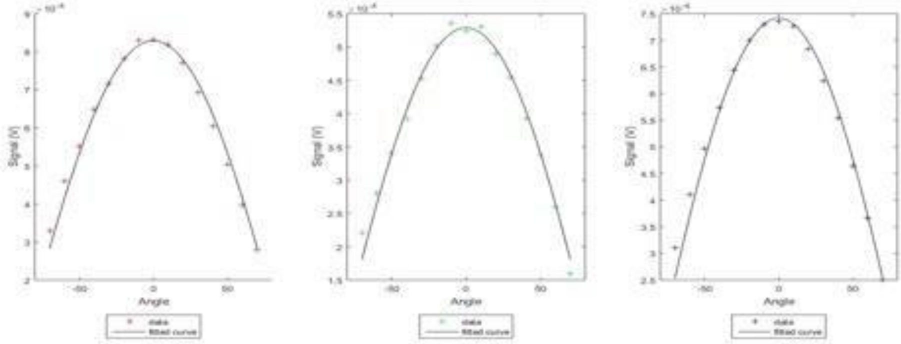


Figure 5. Examples of RGB-ITR reflectance data acquired at 29 meters-distance related to Lambert cosine law.

The good fitting of laser data with cosine trend allows to consider the correction method to reduce distance and angular effects in post processing elaborations according to the following relation:

$$R = \frac{V(\lambda, x, \theta_j)}{V(\lambda, x, \theta_j = 0) \cdot \cos\theta} \tag{4}$$

Eq.(4) has been applied to RGB-ITR laboratory data, visualizing the correction entity through graphics elaborated with MATLAB®suite [9-11] (Fig.6a,b). Fig. 6a shows RGB-ITR raw data as calculated with Eq. (1.1), confirming the necessity of a colour balancing, even within small angular and distance ranges. Fig. 6b displays calibrated data using Eq. (4): the calibration appears to be efficient, performing a satisfactory correction within distance and angular working ranges. As shown in Fig. 6b, the correction is less evident for great incidence angles at average distances (-40° and 40° at 19 meters) and for small angular range at great distances (-20° and 20° at 25 meters). This inaccuracy is caused by second-order factors that reduce the calibration efficiency within wide measurement ranges. These factors are due to, i.e., the lens arrangement and the adopted scanning method of the RGB-ITR system, which causes laser spots distortion on the target, resulting in a signal power loss. For this work, these elements have been not considered in order to focus the attention on the first order factor correction.

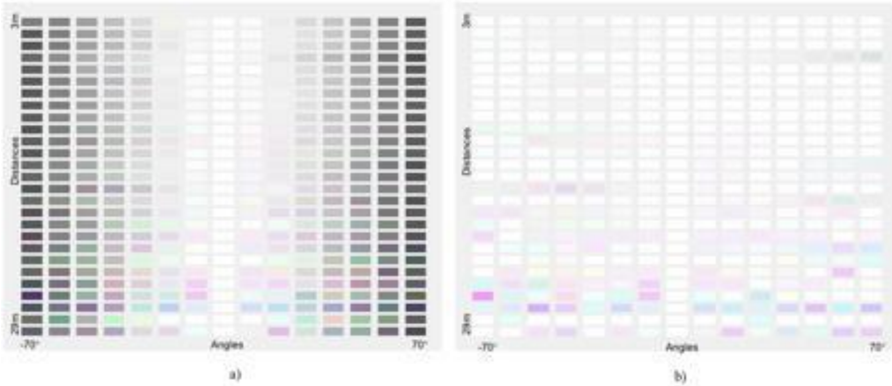


Figure 6 - Colorimetric study on reflectance data: a) raw data; b) data calibrated with Eq. (4)

For the validation of the colour calibration method, Eq. (4) has been applied to real case acquisition: the *Resurrection of the flesh* frescoes inside the Saint Brizio Chapel, belonging to the Orvieto Cathedral (Terni, Italy). In Fig.7-8 are reported RGB-ITR images of the frescoes: Fig.7 shows the image elaborated with the only distance calibration; Fig.8 represents colour calibrated data using Eq.(4) and confirms the efficiency of the correction showing well-defined colours. The main colour representation differences of the two images can be appreciate especially where the incidence angle is wider, in particular in the corners of the Chapel.

Fig.7 – RGB-ITR image balanced with distance calibration.

Fig.8. RGB-ITR images calibrated with distance and colour corrections.

Subsequently to the 2D images manipulation, 3D models have been elaborated using itrAnalyzer software. The following figures show 3D models of the frescoes on the right wall of the Saint Brizio Chapel: Fig.9 presents the RGB-ITR model elaborated from raw data, while Fig.10 reports calibrated data with Eq.4. The colour difference between the following two figures is due to the 3D model point of view that misrepresents the light inside the model.

Fig.9 - 3D model of *Resurrection of the flesh* frescoes with only distance calibration.

Fig.10 - 3D model of *Resurrection of the flesh* frescoes with data calibrated both in distance and in angle.

5 Conclusions

Accurate colour transposition is one of the fundamental aspects of Cultural Heritage digital reproduction. Through the use of a laser scanner prototype and innovative technologies developed at the ENEA Research Centre, this paper proposes a colorimetric analysis of optical signals with two goals: define a methodology inclusive of linear and angular corrections for balancing laser data and reduce *in situ* calibration timing with the application of the complete procedure during post-processing phases.

Laboratory tests have been carried out for the study of the signals' behaviour and the correction entity in order to develop a proper calibration method. The results underlined the strong dependence of colour accuracy with the incidence angle as first factor and notice the participation of second-order factors to the calibration efficiency. Post-processing correction procedure has been applied to the digitalization of *Resurrection of the flesh* frescoes inside the Saint Brizio Chapel in order to verify its feasibility respect to real data. The colour correction of the case study appears to be acceptable and provides an accurate colour transposition in the 3D model. However, further studies are necessary for correcting second order angular effects, especially observed on wider angular ranges. The technique and the results presented should be considered a starting point for a different class of LIDAR scanner, based on the combination of multiple laser wavelengths for a high quality digitalisation of both colour and structure information.

Acknowledgments

A special thanks to Opera del Duomo di Orvieto, which permitted the access to the Cathedral and the study of the Chapel. Thanks also to the ENEA colleagues involved in the instrumentation development and sponsoring (Gerardo De Canio, Giorgio Fornetti, Mario Ferri de Collibus, Marcello Nuvoli).

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3. Colour and Lighting

Lighting to discover the hidden Pompeii colours: the Thermopolium of Vetutius Placidus

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1. Introduction

Archaeological heritage lighting is a stimulating challenge for designers. The need to find a balance between conservation and valorisation raises several issues in terms of systems and structures compatibility, light sources choice, prevention of light-connected damages risks, security [1,2,3]. The lighting goal itself is hard to define: Is the light supposed to simply guarantee safe visit of monuments? Or could it dare to drive people perception, e.g. highlighting specific details, trying to recreate original luminous environments, using scenographic effects or emphasizing visit itineraries? These questions can have different and inventive answers, depending on the archaeological site articulation, its characteristics and its conservation status.
Pompeii is one-of-a-kind archaeological site. Excavations have brought to light an almost-intact town with its houses, shops, theatres, temples, baths. Visiting them, people can come back in time and live ancient Romans life by visiting spaces where they lived.
This implies a particular design approach: differently from other sites, where buildings are mostly in ruin state, in this case, lighting design is at the same time an indoor and an outdoor design. Indeed, some buildings roofs have collapsed, others have maintained their original shape or have been rebuilt. So, visitors continuously pass from outdoor to indoor spaces and vice versa, with the consequent adaptation to very different vision conditions (from photopic to mesopic or scotopic one and vice versa). This can determine visual performance reduction (especially when the passage from a space to another is quick), diminishing the ability in perceiving and appreciating colours, with the consequent loss of some interesting buildings details, neglected because of the inappropriate light conditions [4].
Actually, in most cases, each space of each Pompeii building hides some treasures: Extraordinary frescos or mosaics, characterized by amazing colours, unique both for their documentary and artistic value, are located all around the town, even in the most unexpected places (a cubiculum or a small shop). They should be preserved and valued.
The paper presents the analysis of an ancient Pompeiian *thermopolium*, the so called *Thermopolium* of *Vetutius Placidus*, a sort of "snack-bar", where hot foods and drinks were served. It has a simple structure, but it hides some really interesting examples of Pompeian painting: A stuccoed and frescoed *lararium* (an altar consecrated to *Lares*), representing *Lares*, *Mercurius* and *Dionysus* is located in the shop and the *triclinium* is decorated in "third style". *Thermopolium* lighting conditions were analysed through illuminance, luminance and irradiance measurements. Moreover, frescoes colours were described by means of spectral reflectance measurements and their chromatic coordinates were evaluated. Problems connected to the current lighting conditions were underlined, focusing on frescos colours perception issues.

2. Method

2.1. Case-study description

Thermopolia were a sort of “snack-bars”, where hot foods and drinks were served [5]. They were characterized by a very simple structure: the first room was opened onto the road and was equipped with a counter; big jars, called *dolia*, were recessed in the counter structure and were used to contain products for sale; sometimes, people could eat their own meal sitting in a back room; finally, the owner’s house was annexed to the shop.

The *thermopolium* of *Vetutius Placidus* is located in the north-west corner of the *insula VIII*, situated along *Via dell’Abbondanza*, the main arterial road, connecting the most important city places: the amphitheatre, the theatres, the court, the temples and the thermal baths. Considering the inscriptions found in the house, it probably belonged to *Vetutius Placidus* and his wife *Ascula* [6].

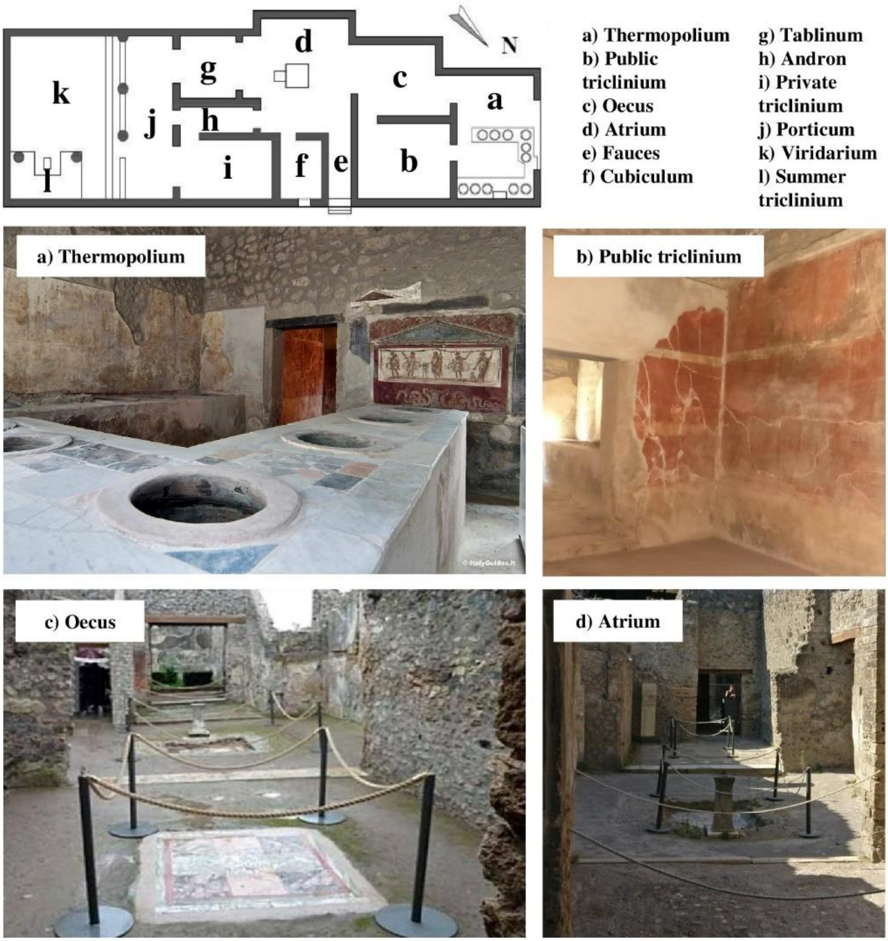

Fig. 1 - Plan and photos of the *thermopolium*.

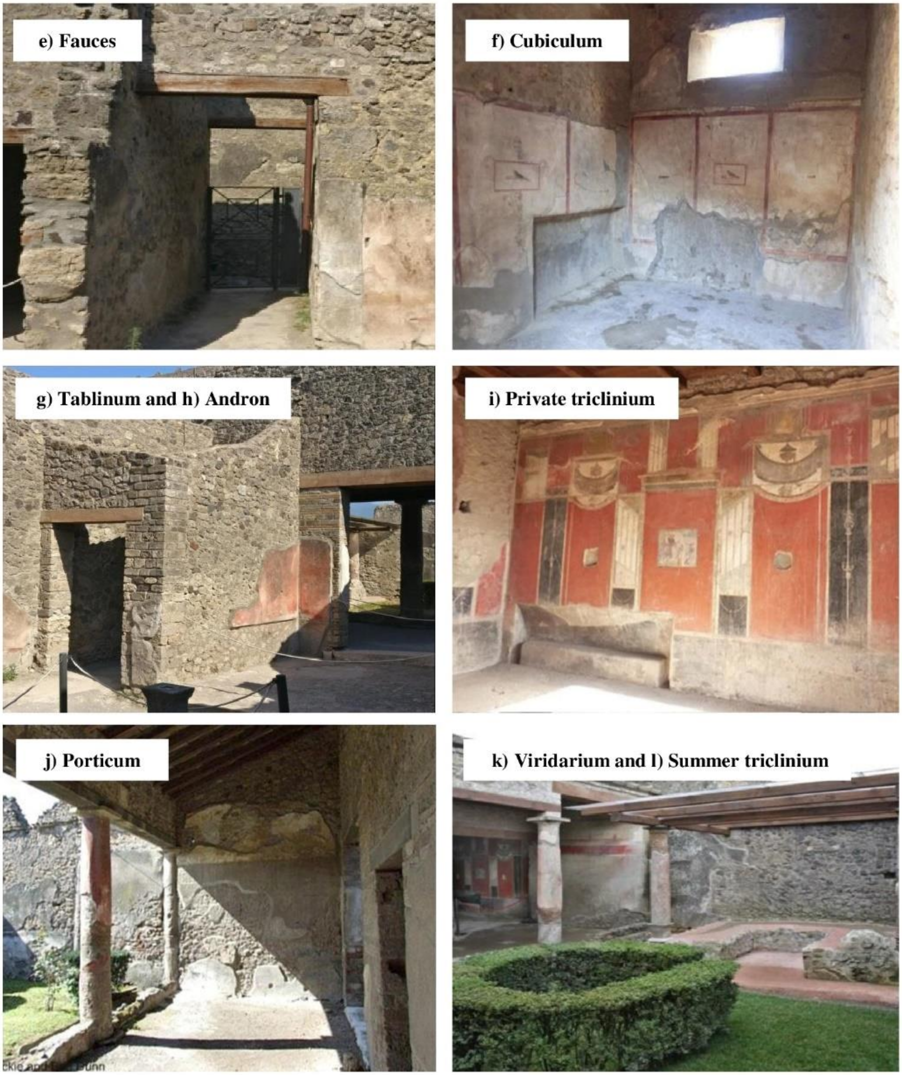

Fig. 2 - Photos of the thermopolium.

As it can be inferred from the plan represented in Fig. 1, the building presents the typical *thermopolium* structure. Going into the house, coming from *Via dell'Abbondanza*, the first room is the actual shop, characterized by the counter with *dolia*. The counter top is preciously decorated with marble flakes and tiles. Two doors connect the shop to a *triclinium* -the dining room- (on the left) and an *oecus* -the living room- (on the right). These two spaces were used by customers to eat meals bought in the shop. The *oecus* brings to an atrium, directly connected to the side street by means of the *fauces* -a corridor allowing the access to the house-. Other three spaces face the *atrium*: a *cubiculum* i.e. the bedroom; a *tablinum* i.e. a sort of living room where the master (*dominus*) hosted his employees (*clientes*); the *andron*, i.e. a

corridor. This one is connected to a private *triclinium*, the dining room used by the house owners. The last part of the house is composed of a *porticum* (the porch) and a *viridarium* (the garden) provided with a summer *triclinium*, a space covered by an awning, to eat outdoor during warm seasons.
Great part of the structure presents the original daylighting conditions, due to the refurbishment works. Indeed, in the *cubiculum*, in the private *triclinium* and in the *porticum* ancient damaged slabs were removed and substituted with wooden beams and planks. Tab. 1 describes the daylighting conditions of each *thermopolium* room underlining the differences between the original status and the current one.

Room	Original daylight conditions	Conservation state of the room structure	Current daylight conditions
Thermopolium (a)	Daylight entered the space through a large door allowing the access to the shop	The room structure is equal to the original one	Sidelit - big door
Public triclinium (b)	The public triclinium received the indirect daylight passing through the two doors connecting it to the thermopolium and to the oecus	The room structure is equal to the original one	Indirect daylight coming from adjacent rooms
Oecus (c)	The oecus received daylight from the adjacent atrium	The ceiling has collapsed	Open-air
Atrium (d)	Daylight passed through the compluvium located in the roof	The ceiling has collapsed and the compluvium ancient structure is not visible	Open-air
Fauces (e)	The fauces received daylight from the adjacent atrium	The ceiling has collapsed	Open-air
Cubiculum (f)	Daylight passed through a small window located in the high part of the wall. Moreover, indirect daylight came into the space from the atrium.	The room structure is equal to the original one	Sidelit – small window Indirect daylight coming from adjacent rooms
Tablinum (g)	The tablinum received daylight from the adjacent atrium	The ceiling has collapsed	Open-air
Andron (h)	The andron received daylight from the adjacent atrium	The ceiling has collapsed	Open-air
Private triclinium (i)	The private triclinium received daylight coming from the adjacent porticum	The room structure is equal to the original one	Indirect daylight coming from adjacent rooms
Porticum (j)	Daylight passed through the colonnade	The room structure is equal to the original one	Sidelit - colonnade along one of the four sides
Viridarium (k)	The viridarium was open-air	The room structure is equal to the original one	Open-air
Summer triclinium (l)	It is part of the viridarium, covered by an awning. It was sourrounded by two walls on two perpendicular sides, whereas the two others were completely open.	The room structure is equal to the original one, but the awning is now semi-transparent.	Sidelit - colonnade along two of the four sides

Tab. 1 - Daylighting conditions in the *thermopolium* rooms

As it can be inferred from Tab. 1, six rooms are completely open-air, and are likely to be characterized by very high daylight illuminance levels. Four rooms are sidelit, but with very different daylight conditions, since daylight sources are of different shapes

and dimensions. Finally, the public and the private triclinium are lit exclusively by indirect daylight coming from adjacent rooms.
As it was reported in the Introduction, *thermopolium* rooms were preciously decorated. In particular, in the shop there is a *lararium* with an interesting fresco representing the family *Genius*, making a sacrifice, the *Lares*, spirits guardian of the house, *Mercurius*, god of the commerce and *Dionisius*, god of the wine. Under this scene, two agathodaemons snakes are represented; they are symbols of prosperity and wealth. Walls of public *triclinium* are frescoed in red and black and the *cubiculum* and the private *triclinium* conserve "third style" frescos. It must be noticed that in the private triclinium there were two panels representing mythological scenes. One of them, portraying Europe rape with Jupiter, is still visible in its original location.
Frescos were interested by recent restoration works aimed at cleaning them from powders. As for the lararium, a retouching intervention was operated on a part added in a previous restoration, in order to make chromatically uniform it to the original one. Moreover, it must be underlined that frescos chromatic characteristics are likely to be altered over time, since the building was buried under ashes for centuries. Moreover, once it was brought to light, given its conditions (some spaces are open-air) the effect of daylight in fading colours can be considerable.

2.2. Measurements

The work is divided in two parts. In the former, current *thermopolium* lighting conditions are analysed. In the latter, frescos optical characteristics are described by means of spectral reflectance measurements.
Currently, the *thermopolium* is exclusively lit by daylight. To characterize indoor conditions, irradiance measurements were performed by means of a Konica Minolta CL-500A spectroradiometer [7] in different points of the ancient structure, during an October sunny day, around 10 a.m.. 12 measurement points were defined: 6 at a horizontal plane located at 0.9 m from the floor (indicated in Fig. 3 with a circle) and 6 at vertical planes. In this case the instrument was positioned at a distance from the floor equal to 1.5 m and oriented according to the directions schematically reported in Fig. 3. Starting from irradiance data, the instrument provides corresponding illuminances and Correlated Colour Temperatures (CCTs).

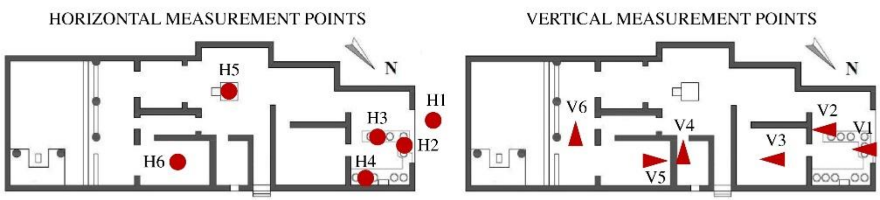

Fig. 3 – Location of horizontal and vertical measurement points.

Thanks to the use of a video-luminance-meter, luminance maps related to some indoor spaces were obtained. The instrument was composed of a digital reflex camera Canon EOS 20D and a photopic filter. The camera was used to take three photos with different shutter times ((2 s, 1/15 s and 1/500 s), in order to acquire information about low, medium and high luminance ranges. Then, starting from these photos, an expressly developed Matlab tool allows to derive corresponding luminance maps.

Finally, by means of a Konica Minolta CM 2600d spectrophotometer [7], spectral reflectance of frescos pigments was measured in the four rooms which better preserved their original decorations: the thermopolium, the public triclinium, the cubiculum and the private triclinium. Specifically, 44 samples of pigments were collected in the 4 rooms. Surfaces of the room walls are generally characterized by colours perceived as white, black and red, whereas parts of the lararium fresco are painted in turquoise and sections of the triclinium central panel are azure, yellow, purple and green.
Starting from spectral reflectance data, L* a* b* coordinates were calculated.

3. Results

3.1. Daylight analysis

Fig. 4 and 5 report irradiances related to horizontal and vertical measurements point. Corresponding CCTs are reported on the graphs.
As for the horizontal ones, it can be noticed that H1, outside located, presents the typical trend of a D65 standard illuminant, corresponding to a 9149 K CCT. A similar trend can be recognised for H2 and H6, respectively located on the top of the counter, very close to the shop enter (see Fig. 3) and in the private triclinium, at the centre of the room. However, in these two cases, the daylight spectrum is slightly modified by the interaction with architectural surfaces, that, given their optical characteristics, absorb small and medium wavelength radiations determining that the central part of the spectrum assumes a more horizontal trend compared to the H1 one. This determines a significant reduction of the CCT, that assumes values equal to 5040 K and 5227 K for H2 and H6 respectively. H3 and H4 are located in the part of the *thermopolium* more distant from the door. In these two cases, daylight interreflections are such that small and medium wavelength radiations are strongly absorbed and, consequently, the first part of the spectrum (till about 610 nm) assumes an increasing trend. The corresponding CCTs are 3903 K and 3464 K. As regards H5, the daylight spectral distribution is completely different. H5 is positioned at the centre of the atrium (see Fig. 3), that is completely open-air. Considering the time of the day, daylight entering the space is essentially skylight, so irradiance is high considering small wavelengths and start decreasing from 460 nm on. In this case the CCT is very high and specifically equal to 10780 K. As for vertical measurement points (Fig. 5), the irradiance trends are very similar to the horizontal ones. In particular, it can be observed that V1, V2 and V3 have a trend similar to the H3 one. They are located in the *thermopolium* and in the public *triclinium* and are all oriented towards the shop enter. For these three points the CCTs are very similar and equal to 4122 K, 4047 K and 4054 K. On the contrary V4, V5 and V6 (located in the *cubiculum*, the private *triclinium* and the *porticum* respectively) are characterized by spectra more similar to the H2 one. The corresponding CCT values are: 5426 K, 5167 K and 4930 K.
Fig. 6 reports illuminances measured at horizontal and vertical measurement points. Both for the horizontal and for the vertical ones, it can be observed that daylight gradients are very significant. Very high illuminances (greater than 2200 lx) are registered at H1 (outdoor located) and V1 (located in the *thermopolium*, very close to the door) and illuminances equal to 5818 lx and 4930 lx are registered in the atrium and in the *porticum* respectively. H2, V2 and V5, despite indoor located, are

characterized by illuminance values comprised between 758 lx and 983 lx, whereas for the other measurement points illuminances range from 152 lx to 261 lx.
Differences in indoor daylight levels are confirmed by luminance maps of Figure 7, where white labels report luminance values in cd/m^2 (indicated as *Index*) related to some significant points. Maps demonstrate that indoor luminance contrasts are very high. For example, considering the cubiculum, most of the space is characterized by luminance levels ranging from 0 cd/m^2 to 15 cd/m^2, but, considering points corresponding to the access door, they achieve luminance values equal to about 600 cd/m^2.

HORIZONTAL MEASURES

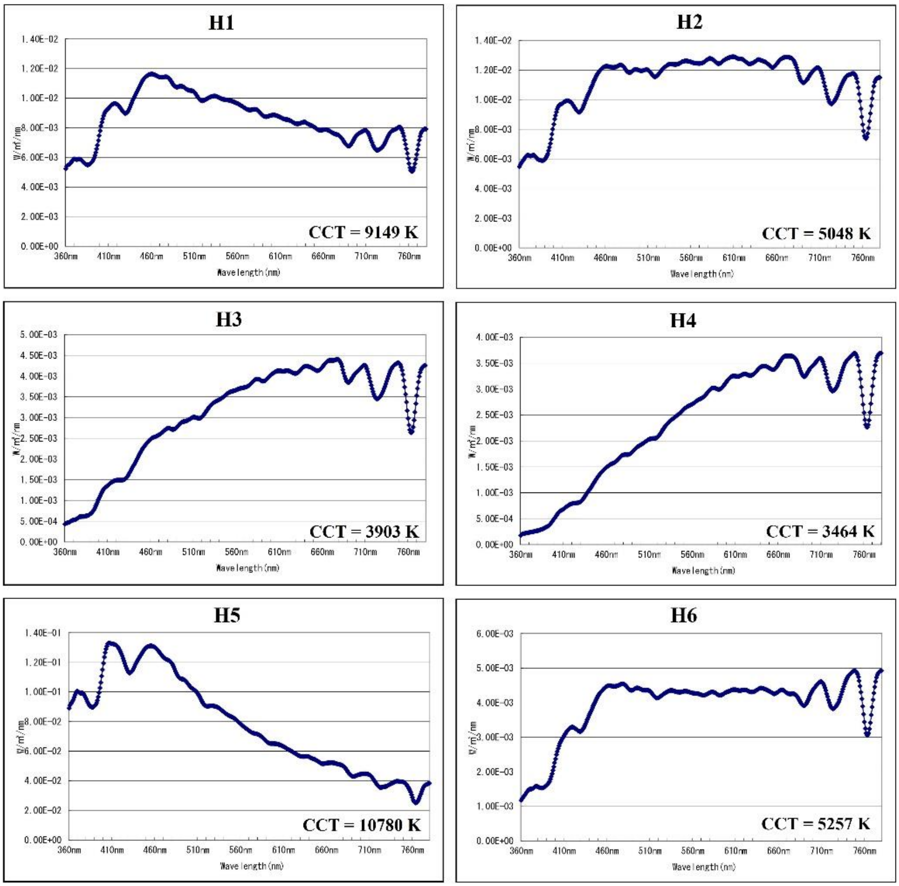

Fig. 4 - Daylight irradiance related to horizontal measurement points.

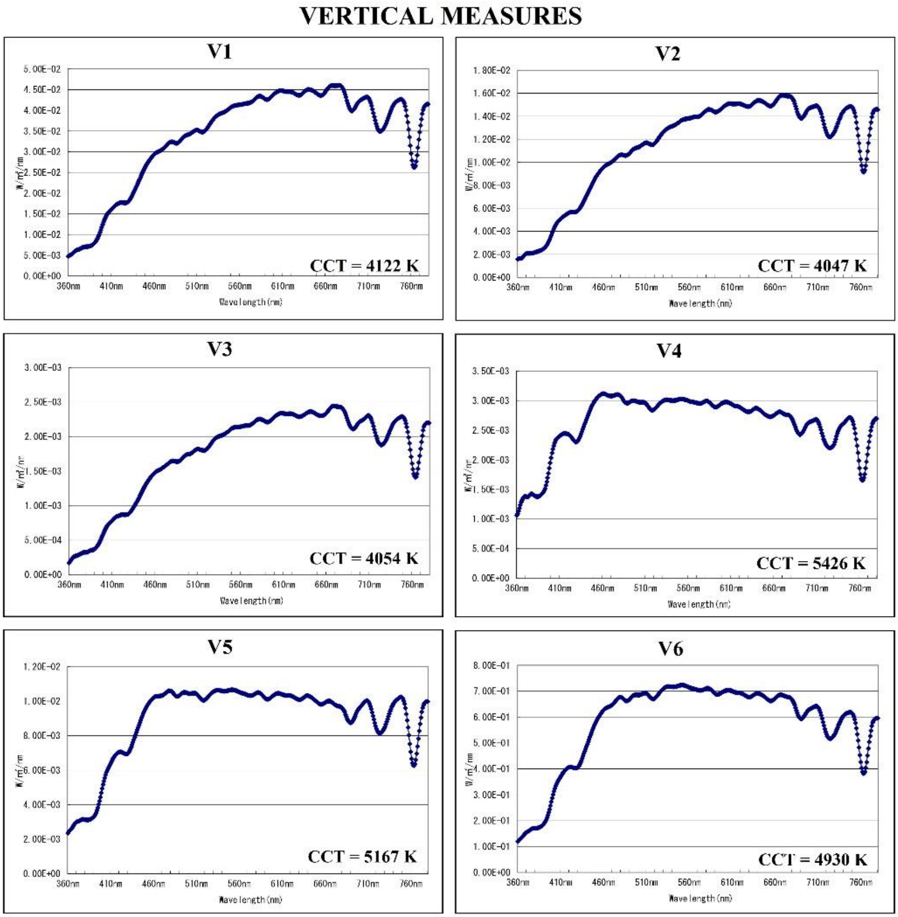

Fig. 5 - Daylight irradiance related to vertical measurement points.

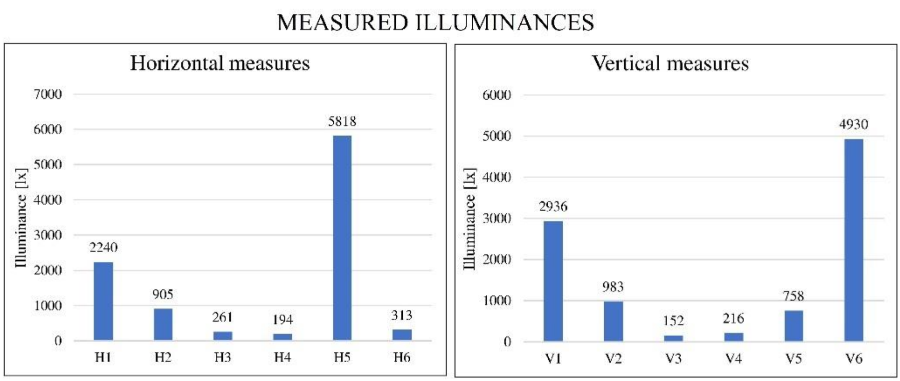

Fig. 6 - Daylight illuminances measured at horizontal and vertical measurement points.

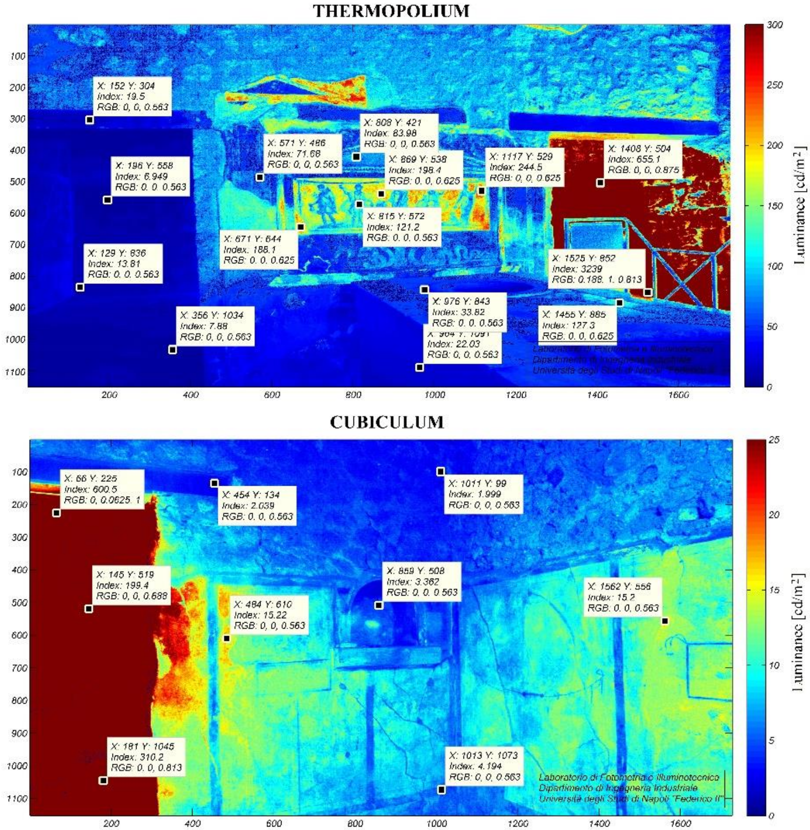

Fig. 7 – Luminance maps related to the *thermopolium* and the *cubiculum*.

3.2. Architectural surfaces chromatic analysis

Graphs of Figures 8-10 report spectral reflectance of the measured frescos pigments. Specifically, in Fig. 8 are reported results related to pigments of wall frescos located in the public triclinium, in the *cubiculum* and in the private *triclinium*, characterized by the use of white, black and red painting; whereas Fig. 9 and Fig. 10 report a focus on the fresco of the *lararium* and on the central panel of the *triclinium*, presenting more colours and shades. In each figure, data related to surfaces perceived as black and white are separated from those related to coloured surfaces.

As it can be inferred from the graphs, surfaces perceived as white are characterized by an increasing spectral reflectance trend, with values at 360 nm ranging from about 10% to about 30%, depending on the considered sample and at 740 nm ranging from about 40% to about 70%. As for some samples, this increasing trend is characterized by an almost constant slope. As for some others, an inflection point can be observed corresponding to the central part of the spectrum and determining a slope reduction. As regards colours perceived as black, they are all characterized by an almost horizontal trend, with spectral reflectance values generally comprised between 5% and 15%. B2 and B3 in Fig. 8 are the only two exceptions. Specifically, B3 is characterized by a trend similar to that of red surfaces. All the measured red surfaces are indeed characterized by an almost constant trend in the range 360-540 nm (spectral reflectance is always lower than 30%), then a brusque slope increase can be observed until about 610 nm, finally the last part of the spectrum is increasing but the slope is lower (the maximum spectral reflectance value at 740 nm is registered for R4 and is about 60%). Turquoise and azure trends are really interesting. These pigments always register the maximum spectral reflectance at 740 nm (until about 60% for the A6 in Fig. 10). On one hand, as for the turquoise samples, they generally have an increasing trend until 520 nm, then it starts to slightly decrease until about 630 nm and then increases again. On the other hand, the azure samples are characterized by very different trends.

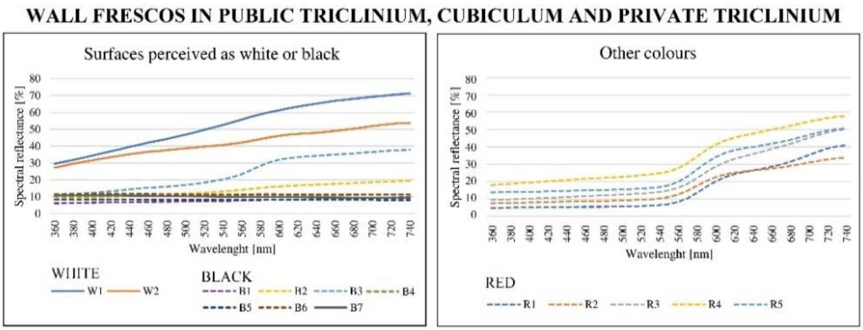

Fig. 8 – Spectral reflectance related to wall frescos in public triclinium, cubiculum and private triclinium.

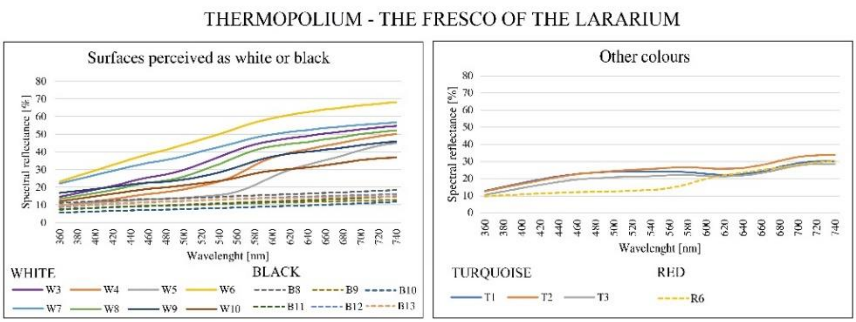

Fig. 9 - Spectral reflectance related to the fresco of the lararium.

Fig. 11 and Tab. 2-5 represent for each sample the L* a* b* coordinates in the CIELab colour space. As it can be inferred from the graphs and the tables, most of the samples are in the first quarter, the yellow-red one, and they are located very close to the centre, meaning that they are all characterized by low saturation. White and black samples do not always coincide with the centre, the white sample farthest from the centre has a* and b* equal to 12.76 and 21.47 respectively; the black one has an a* value equal to 11.63 and a b* value equal to 17.26. Red samples are concentrated along a ray determining with the a* axis an angle equal almost to 40°. The only samples located in the blue-green quarter are the turquoise, the azure and the green ones. They are all very close to the centre as well.

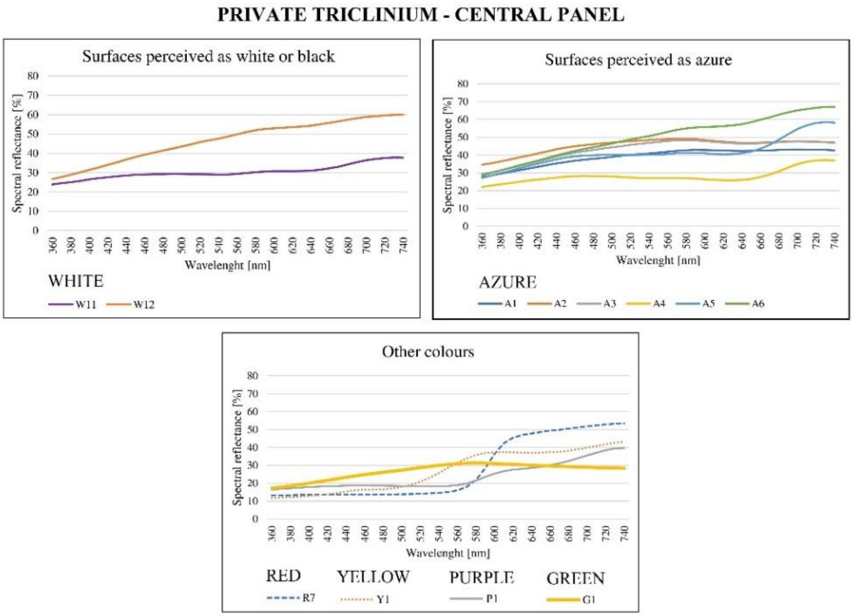

Fig. 10 - Spectral reflectance related to the central panel in the private triclinium

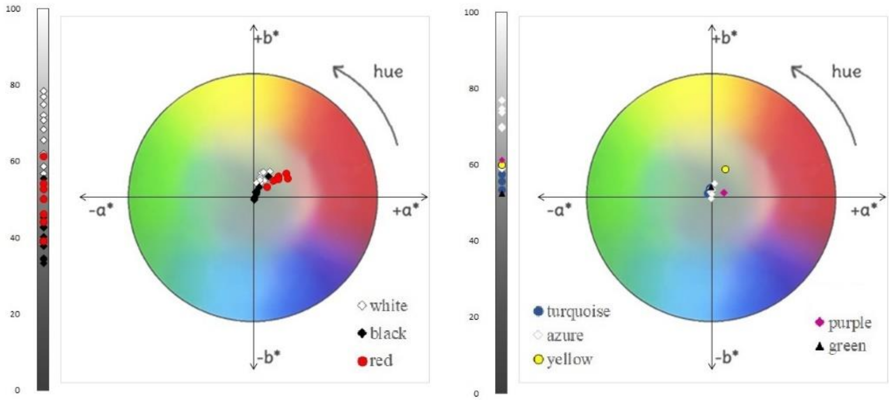

Fig. 11 – L* a* b* values of the observed samples

	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12
L*	68.48	58.89	50.43	77.08	72.2	65.76	62.14	57.02	78.58	70.87	61.35	75.11
a*	5.87	12.76	14.44	4.22	3.9	7.3	7.87	5.11	4.37	3.19	1.22	1.84
b*	20.4	21.47	13.56	16.37	14.12	20.85	13.94	12.08	14.46	7.63	1.49	12

Tab. 2 - L* a* b* values related to pigments perceived as white

	B1	B2	B3	B4	B5	B6	B8	B9	B10	B12	B13	B14	B15
L*	45.35	38.82	34.7	39.62	43.03	42.82	33.52	44.04	55.56	39.08	34.46	40.4	37.96
a*	1.52	1.19	1.88	1.8	1.44	0.8	1.53	4.18	11.63	0.53	0.02	0.15	-0.24
b*	4.22	4.4	4.9	5.27	5.18	4.38	2.95	8.5	17.26	0.81	-0.25	-0.42	-1.58

Tab. 3 - L* a* b* values related to pigments perceived as black

	R1	R3	R4	R5	R6	R7	R8
L*	46.24	39.18	44.36	50.18	61.48	54.32	52.93
a*	10.11	25.49	18.51	19.3	15.51	19.55	27.03
b*	8.62	19.49	15.79	17.11	14.14	15.3	15.51

Tab. 4 - L* a* b* values related to pigments perceived as red

	T1	T2	T3	A1	A2	A3	A4	A5	A6	Y1	P1	G1
L*	55.76	57.65	53.46	70.21	74.82	73.85	59.06	69.78	76.97	60.09	52.52	61.34
a*	-2.67	-1.14	-1.22	-0.04	-1.61	-1.29	-1.12	-0.32	1.71	10.22	9.19	-0.98
b*	2.9	6.6	5.23	6.32	4.45	7.28	-0.78	2.77	11.49	22.97	3.9	8.75

Tab. 5 - L* a* b* values related to pigments perceived as turquoise, azure, yellow, purple and green

4. Conclusions

The paper presents results of daylight and spectral reflectance measurements performed in the Thermopolium of Vetutius Placidus in Pompeii. Results underlined the following problems:

- Visiting the Thermopolium, passing from a space to another, daylight illuminance levels are very different and luminance contrasts remarkable, determining that visitors' visual system has to continuously adapt to different conditions, with the consequent difficulty in perceiving artworks located in the structure;
- Architectural surfaces have a relevant role in modifying the spectrum of daylight entering the space. In particular, they absorb low wavelengths radiations, being characterized by higher spectral reflectance values corresponding to high wavelengths;
- Surfaces colours are all slightly saturated and are mostly concentrated in the first quarter of the CIELab colour space.

Limits of current light conditions could be overcome thanks to a proper lighting design able to improve visitors' experience. Daylight and electric light integration should be used as a tool to reduce visual discomfort. For example the installation of luminaires in the spaces characterized by very low illuminance levels would reduce luminance contrasts between these spaces and the adjacent ones and would solve visual adaptation problems along the visit path. Moreover, electric light could be used to highlight frescos found in the building. For this purpose, the spectrum of the light sources should be chosen according to the pigments spectral characteristics, in order to enhance their chromatic perception.

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The design of a practical experiment to explain the color constancy

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Abstract

In this research, aimed to demonstrate color constancy, a 3D device has been specifically designed and built to isolate the observer from the effects of ambient light that can affect the results of the experiment and also change the lighting spectrum in the experiment. This device allows you to check the effects of lighting variations on color sets both in a context and isolated. The difference, compared to imaging-based systems, is that with this apparatus you can evaluate the perceptual difference of these two conditions (context or isolated) at the same time as the lighting changes, being able to observe 4 different chambers. The device is also portable and has been designed to be self-explanatory.

1. Introduction

The possibility for science to describe and represent human visual perception through mathematical models meets considerable difficulties when, going beyond the retina, it tries to describe how the perceptive sensation of the image in our brain is created. The way human beings see the world around them is a mental representation that is not strictly correlated with its real physical and radiometric nature; this is a research topic also known as color appearance [1]. This can be demonstrated by various laboratory experiments and also by many optical illusions. For the purposes of teaching lighting and color design, the teacher should deal with basic experiments that demonstrate the differences between the objective physical reality of the environment and the human subjective perception.

The environment around us is complex: it has a geometric, material nature and a luminous dimension that allows us the visual perception. If it is true that light brings visual information from the environment to our mind, it is also true that, from the physical point of view, this light information can be extremely variable, despite considering the same environment, depending on the position of the observer, the time of day, the weather conditions, the season, the materials and the physical characteristics of light. This applies to both natural and artificial light: there are continuous variations in spectral distribution, direction and intensity that are compensated for by our visual perception [2]. This happens because this light complexity requires to be adapted to our needs and our desire to perceive it, if possible, in a stable way; this is the task performed mostly by the cerebral cortex [3]. In the lighting and color design these aspects are almost never taken into consideration while they should be introduced into the training path, with the theory supported by experimental practice [4].

Perceptual constancy is a fundamental mechanism of human visual perception. It is thanks to the perceptual constancy that we are able to see the colors of the surrounding environment in a relatively stable way, even if the lighting conditions change a lot generating very variable luminance and spectral distribution levels, in various real situations [5].

2. The Color Constancy

The color constancy is the ability of the human visual system to compensate, within wide margins, changes in the spectrum of light reflected by objects due to spectral variations of lighting. Indeed, the spectrum of light that reaches our eyes is the result of the interaction between the light that illuminates the surfaces and the reflective properties of the objects.
As a consequence of the physical reality it could be verified, for instance, with spectrophotometric measures, that a white sheet illuminated by a red light and a red sheet illuminated by a white light can reflect a chromatic signal of the same spectral composition but, thanks to the phenomenon of color constancy, our system visual is able to make us perceive the white sheet as white and the red sheet as red.
Since the days of ancient Greece, it has been considered the question of the variation of some colors of fabrics when they are put from natural light to that of oil lamps. One of the first scientists who observed and described the phenomenon was Gaspard Monge with his experiments on color observation through colored glass [6].

Fig. 1 – Example of an image that is used to explain the phenomenon of color constancy. In the image has been completely eliminated the green component, also the sky is violet tending to magenta. Nevertheless, green shades are perceived on the tree and the sky is perceived as bluish. The effect is much more evident when the image is projected into a dark room without other sources of light. Photo by Maurizio Rossi.

Most of the experiments on color perceptions useful to visually explain the effect of color constancy are carried out using imaging device in order to observe color compositions [7][8]. Some researchers have also defined material reflectance and possible illuminants datasets, useful to the evaluation of mathematical models that try to describe the color constancy [9][10]. In this paper, however, the interest is not in the question of descriptive mathematical models, but in the practical perception with the aim of lighting and color design teaching. To better understand the functioning of perceptual constancy, it is advisable to draw a comparison between vision and photography.

Until a few years ago, making beautiful photographs of any scene in uncontrolled lighting situations, with analogic cameras based on photosensitive film, required a higher level of professional competence, almost at a professional level. Otherwise underexposed, overexposed, over-contrasted, under-contrasted or strongly dominant color photographs were obtained. In fact, photography simply captures the light received by the lens and then measures the objective physical luminances of the scene. Today, thanks to the researches on imaging technologies, modern digital cameras have algorithms that try to simulate human perceptual constancy, based on the setting of some known average lighting conditions for the scene that you want to shoot [11]. The user can manually choose the type of scene to allow the camera to adapt appropriately to the average lighting conditions that are predictable in that environment. Instead, the human visual system does everything automatically with relatively quick response times that depend on the type of adaptation required; in fact, it is able to adapt to the increases and decreases in lighting that can range over several orders of magnitude, but it is also able to distinguish the colors correctly when the real spectral information received from the retina is strongly modified by the lighting spectrum.

3. The experimental box

To demonstrate the phenomenon of color constancy, a 50x30x30 cm size box was created, in which it is possible to have two kind of lighting on two types of different color samples, for a total of four possible observable conditions.

It has been used a LED white light source with two Lumileds Luxeon Star White 4.900K and its spectrum has been modified through the use of colored filters to obtain two different illuminations that tend one to azure and the other one to pink, thus with very different spectral distributions. The spectral distributions of the white light source, and the azure and pink lighting, were measured with a Spectra-radiometer Minolta CL-500 (Figure 2).

As can be seen from the spectrum and chromaticity shown in the CIE chromaticity diagram (Figure 3), the pink light has a noticeable short-wavelength content that brings it closer to a light magenta; anyway this did not affect the experiment negatively.

The four different observation scopes have been separated to avoid interference in lighting and color perception (Table 1). It is important to remember that the photographs shown in Table 1 are not perceptually equal to the perceptive sensation that we have, in real life, observing the experiment. In the two observation conditions on the left the richness of colors present allows the brain to distinguish them correctly through a comparison between the various parts of the image and the presence of white; this is also observable in the photography in Table 1. Differently, in the other two observation conditions on the right, the individual colors are decontextualized in a black background. Difficulties arise from the absence of a white sample and a colored context, so that we are not able to clearly define the two colors that are at the top and at the bottom of each one.

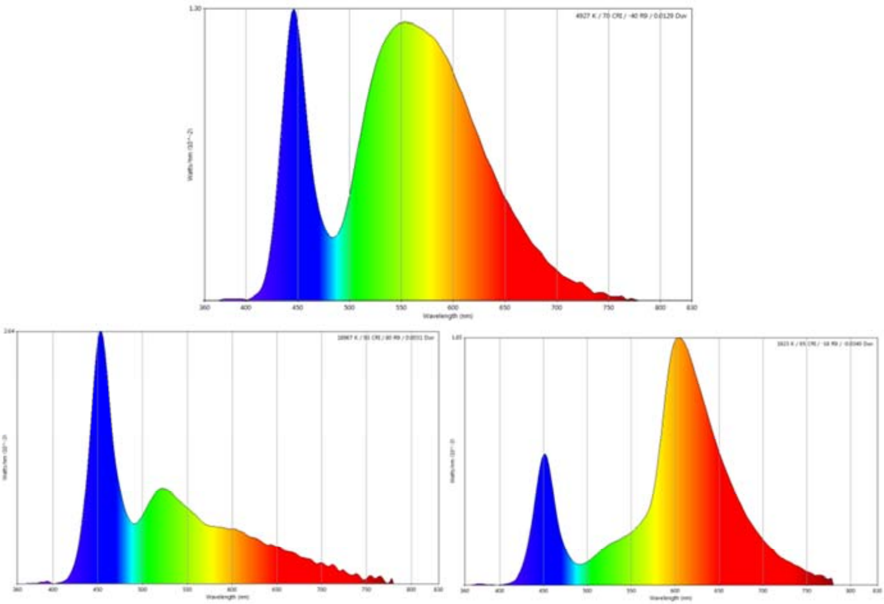

Fig. 2 – Above: the spectral power distribution of the white light source.
Under on the left: the azure lighting; under on the right: the pink lighting.

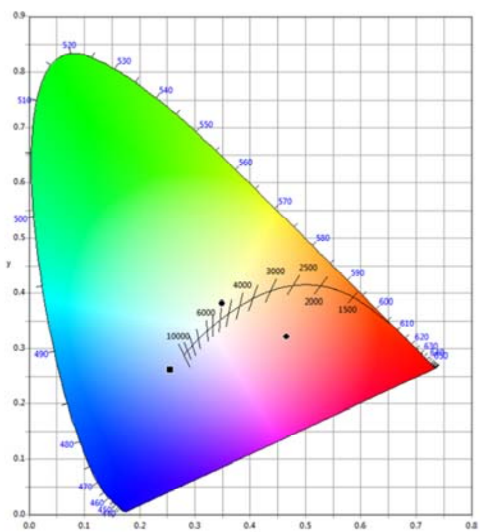

Fig. 3 – The chromaticity of the three illuminants in the CIE 1931 diagram. ● White light. ■ Azure light. ♦ Pink light.

	Colors in context	Colors not in context
Azure lighting		
Pink lighting		

Tab. 3 – The four observation conditions.

The experiment box is made of five separate chambers, one of which is dedicated to the light source and the other four are dedicated to the observation of the colors. In order to isolate the experiment from the ambient light, it is possible to see only a single chamber at a time, separately from the others, through holes on the front side of the box.

The upper part of the box is dedicated to the light sources and has all its interior surfaces painted in diffusing white in order to achieve a diffused lighting condition without highlights. From the luminous chamber the light passes down to the four color observation chambers through 2 red filters and 2 blue filters.

In the lower four rooms dedicated to the color samples, the box is internally lined with opaque black velvet in order to avoid, as much as possible, mutual reflections of colors towards the walls and vice versa. In this way it is guaranteed that the observer sees only the result of the reflection of the light source on the color sample; so the light that reaches the eyes, for each individual color sample, is only the result of the interaction between the lighting spectrum and the spectral reflectance of the color sample (Figure 4). In order to be self-explanatory, the box is also equipped, on its lower side, with an illustrative card that explains the experiment and which can be pulled out if necessary.

4. Conclusions

One of the most interesting things for the students to observe is that the phenomenon of chromatic constancy can diminish considerably if the observer receives only colored patches in the field of view without a reference of maximum reflectance, that is white, and without other adjacent colors. This phenomenon is clearly observable, in real life, in the two images on the right of Table 1, while it is less visible in the figures printed in this paper in Table 1. This effect is mostly noticeable from the truth when the observer tries to clearly define the two colors at the top and at the bottom: are they yellow, orange, green, brown?

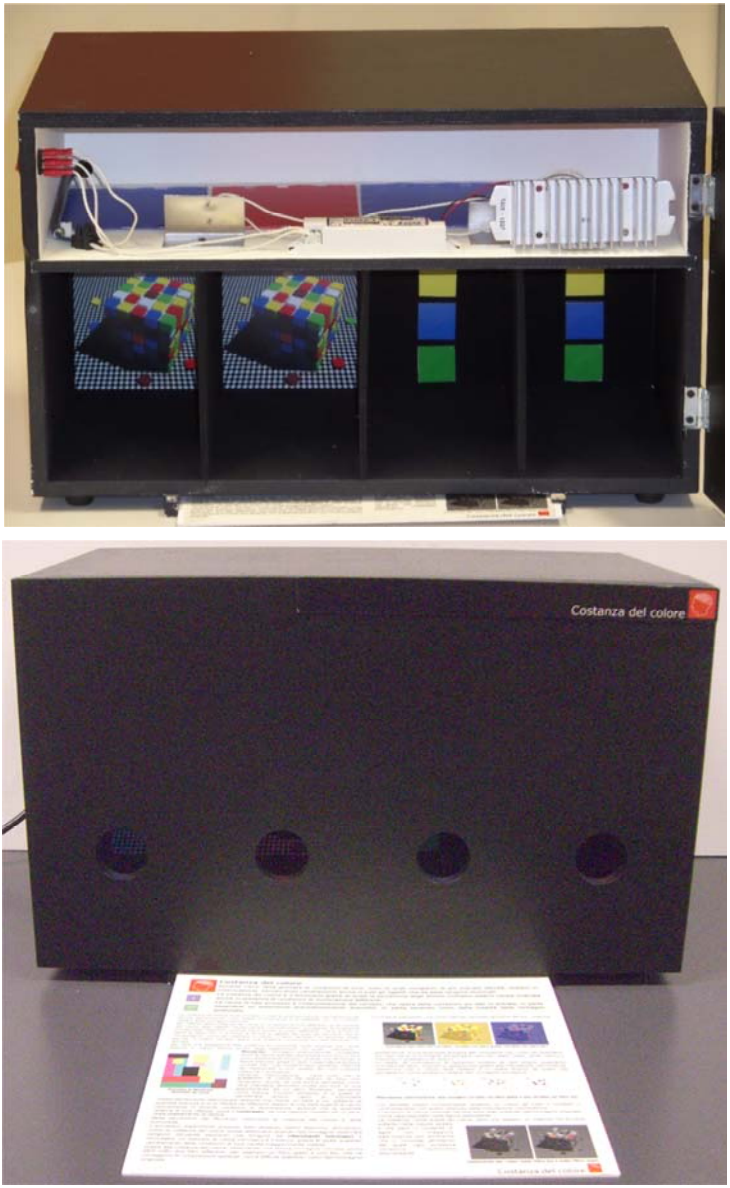

Fig. 4 – The color constancy box opened and closed.

Differently, by introducing a more general context around the color samples, the chromatic constancy is observable in a more accentuated manner, as it happens in real life. The importance of the context is fundamental. The presence of white and other adjacent colors helps the visual system to normalize the chromatic signal received by the three fundamental bands of the tristimulus and to decrease the color drift due to the illumination spectral power distribution.
Finally, by opening the experiment box, with the entrance of the ambient light present in the environment, the observer can see the way in which the color perception changes and understand two fundamental aspects of the color constancy: the effects due to the variation of the lighting spectrum and the importance of the contextualization of colors in the visual perception of the world around us.

Acknowledgments

A special thank to Barbara Ripamonti for the contribution to the setup of the experiment box, to Andrea Siniscalco for the retrieval of the necessary materials and to Fulvio Musante for the measurements made.

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300 years of the second edition of Newton´s opticks and its news in art and science

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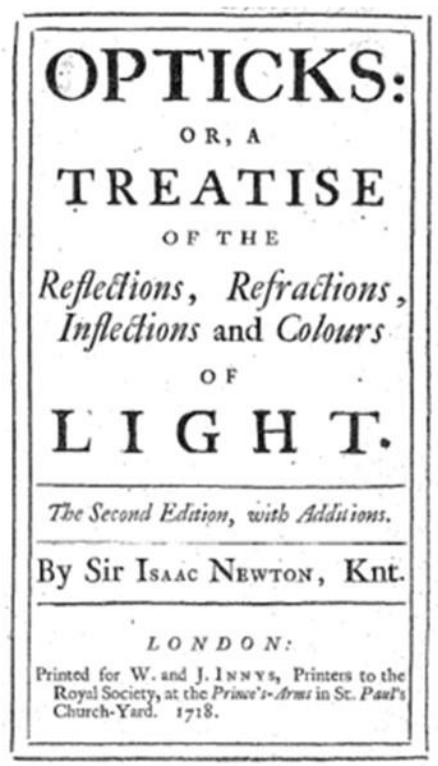
1. Introduction

Sir Isaac Newton, in his long life, 1643-1727, gave us two great works: the "Principia" and the "Opticks". The first writes a new dynamic for terrestrial physics and the planets of the solar system and the second describes optical phenomena such as double refraction, the decomposition of light into the atmosphere (rainbow), and various phenomena involving reflection (including the invention of the telescope that leads its name), deflection (inflection), diffraction. This second masterpiece of the Scientific Revolution started one hundred years ago with the publication of Nicolaus Copernicus' *De Revolutionibus orbium coelestium* (1543) when Newton was born (1643).

By the end of the seventeenth century Isaac Newton was known for his exceptional works in the field of Physics and Mathematics and had been assembled in the Principia. Newton entered into numerous intellectual disputes, especially with Leibniz and Hooke. The latter, inventor of the microscope and author of the excellent "Micrographia", was the one who had intuited, before Newton himself, the genesis of the gravitational force as inversely proportional to the square of the distance. This fact, revealed by Edmond Halley, left Newton in a field hostile to Hooke since at the time this relationship came to light, Newton was preparing the manuscripts of his "Principia."

The intellectual fight between the two thinkers will last a long time. However, Hooke dies in 1703, which may explain Newton's decision to publish his "Opticks" (fig. 1) a year later [1]. Newton's optical discoveries, which had been kept secret for almost 30 years, were revealed in a book that would be a landmark for optical science with reflections not only in this area but especially in the Arts (color theory) and Astronomy/Cosmology (light ray deflection) and light-matter conversion.



OPTICKS:

OR, A

TREATISE

OF THE

Reflections, *Refractions*, *Inflections* and *Colours*

OF

LIGHT.

The Second Edition, with Additions.

By Sir ISAAC NEWTON, Knt.

LONDON:

Printed for W. and J. INNYS, Printers to the Royal Society, at the *Prince's-Arms* in St. *Paul's* Church-Yard. 1718.

Fig.1- 2nd. Edition of the "Opticks".

The book is an extraordinary contribution to the comprehension of the light and optical phenomena, by nature (Fig.2, the rainbow) and by elaborated experiments (like Fig.3, when it is demonstrated that a refracted light is not refracted again).

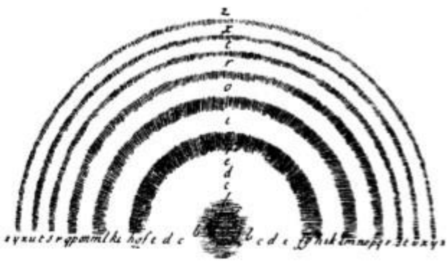


FIG. 2.

blue, nor yellow, and the red was very imperfect and dirty. Also the succeeding Colours became more and more imperfect and dilute, till after three or four revolutions they ended in perfect whiteness. Their form, when the Glasses were most compress'd so as to make the black Spot appear in the center, is delineated in the second Figure; where *a, b, c, d, e: f, g, h, i, k: l, m, n, o, p: q, r: s, t: v, x: y, z*, denote the Colours reckon'd in order from the center, black, blue, white, yellow, red: violet, blue, green, yellow, red: purple, blue, green, yellow, red: green, red: greenish blue, red: greenish blue, pale red: greenish blue, reddish white.

Fig.2 - The rainbow by I. Newton (a piece of the original text, depicting the colors of the rainbow.

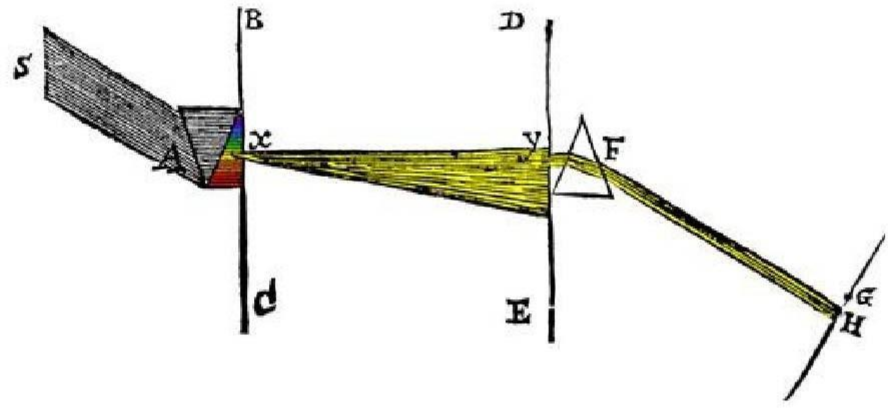


Fig. 3 - The experiment of the refraction of the light (dispersion by a prism).

The death of Leibniz seems to have encouraged the second edition of the Opticks between 1717-18 with new "queries" (14 expanded to 31) that would prepare a fertile field of research for the next 300 years, both for the theory of light, colors and cosmology.

2.The “Queries”

Newton, in his book III (2nd.edition) presents 31 questions ("queries") concerning the optical phenomena unveiled by his 30 years of previous experimentation. It is important to quote them in their original context to demonstrate how Newton in these 30 years of study on optical phenomenology has been able to anticipate

phenomena that are closely related such as gravitation, cosmology, and nuclear and particle physics. We have chosen four of these questions to demonstrate the ability to question Nature in Newton's work and how these issues have established conceptual and procedural milestones that have moved science from the eighteenth century to the twenty-first century:
Query I: Do not bodies act upon at a distance, and by their action bend its rays, and is not this action (*cateris paribus*) strongest at the least distance? (Fig. 4).

Query 1. Do not Bodies act upon Light at a diſtance, and by their action bend its rays, and is not this action (*cæteris paribus*) ſtrongeſt at the leaſt diſtance?

Fig. 4. Query I.

Query 5. Do not Bodies and Light act mutually upon one another, that say, Bodies upon Light in emitting, reflecting, refracting and inflecting it, and Light upon Bodies for heating them, and putting their parts into a vibrating motion wherein heat consists? (Fig.5).

Qu. 5. Do not Bodies and Light act mutually upon one another, that is to ſay, Bodies upon Light in emitting, reflecting, refracting and inflecting it, and Light upon Bodies for heating them, and putting their parts into a vibrating motion wherein heat conſiſts?

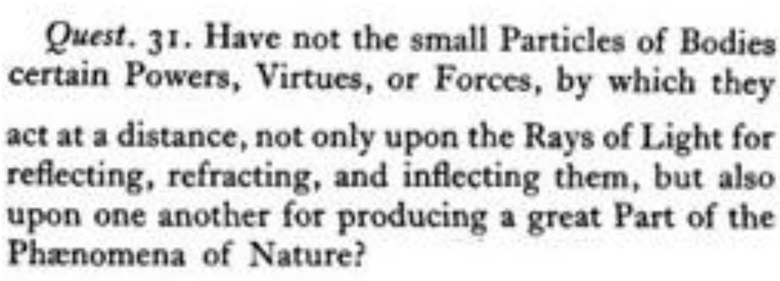
Fig.5 - Query 5.

Query 30. Are not gross Bodies and Light convertible into one another, and may not Bodies receive much of their Activity form the Particles of Light which enter their Composition? (Fig. 6).

Quest. 30. Are not gross Bodies and Light convertible into one another, and may not Bodies receive much of their Activity from the Particles of Light which enter their Composition? For all fix'd Bodies being heated emit Light so long as they continue sufficiently hot, and Light mutually stops in Bodies as often as its Rays strike upon their Parts, as we shew'd above. I know no Body less apt to shine than Water; and yet Water by frequent Distillations changes into fix'd Earth, as Mr. *Boyle* has try'd; and then this Earth being enabled to endure a sufficient Heat, shines by Heat like other Bodies.

Fig.6 - Query 30.

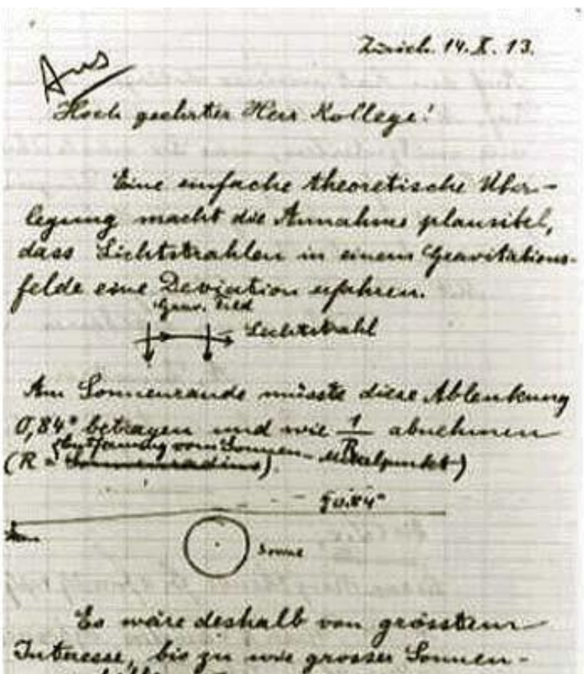
Query 31. Have not the small Particles of Bodies certain Powers, Virtues, or Forces, by which they act a distance, not only upon the Rays of Light for reflecting, refracting, and inflecting them, but also upon one another for producing a great Part of the Phenomena of Nature? (Fig.7)



Quest. 31. Have not the small Particles of Bodies certain Powers, Virtues, or Forces, by which they act at a distance, not only upon the Rays of Light for reflecting, refracting, and inflecting them, but also upon one another for producing a great Part of the Phænomena of Nature?

Fig. 7 - Query 31.

These three questions chosen from Book III of Newton's Opticks demonstrate a questioning capacity of Nature that advanced a whole field of research that would result, three centuries later in Einstein's Relativity (the deflection of a ray of light by the gravitational field of a star – Fig. 8), and the energy-matter conversion ($E = m.c^2$).



Zürich. 14.X.13.

Hoch geehrter Herr Kollege!

Eine einfache theoretische Überlegung macht die Annahme plausibel, dass Lichtstrahlen in einem Gravitationsfelde eine Deviation erfahren.

Grav. Feld

Lichtstrahl

Am Sonnenrande müsste diese Ablenkung 0,84" betragen und wie $\frac{1}{R}$ abnehmen (R = Entfernung vom Sonnen-Mittelpunkt).

0,84"

Sonne

Es wäre deshalb von grösstem Interesse, bis zu wie grosser Sonnen-

Fig.8 - Einstein's 1913 notes on the deflection angle (inflection) of the light path of a star in the vicinity of the Sun (estimated value = twice the value predicted by Newton).

3.Final considerations

Newton's work, as can be seen from the four questions exposed, is not overtaken by the modern theories of General Relativity and the paradigm of the Big Bang. Even the deflection of the ray of light, supposedly measured during the total eclipses in 1919 in Sobral (Brazil) and Prince (Africa) involving the stars of the Constellation of Hyades, is involved in an interpretation dispute, since the best values obtained, those of Sobral, confirm the prediction coming from the Newtonian theory, whereas those of Prince lean towards the values of the General Relativity of Einstein (deflection twice).

We know that the paradigm of the Big Bang is based on three pillars: the synthesis of the light elements, the cosmic background radiation, the redshift. All three "great proofs" can be found in Newton's seminal work, and in the questions presented here: the interaction of matter and energy, involving optics, color theory, thermodynamics, field theory (modern conception).

Newton is the link between the past and the future, from Aristotle to Einstein: in Aristotle, in his *Physis* and *Meteorologica*, involving the explanation of the atmospheric phenomenon of the rainbow (see Fig.9 and 10).

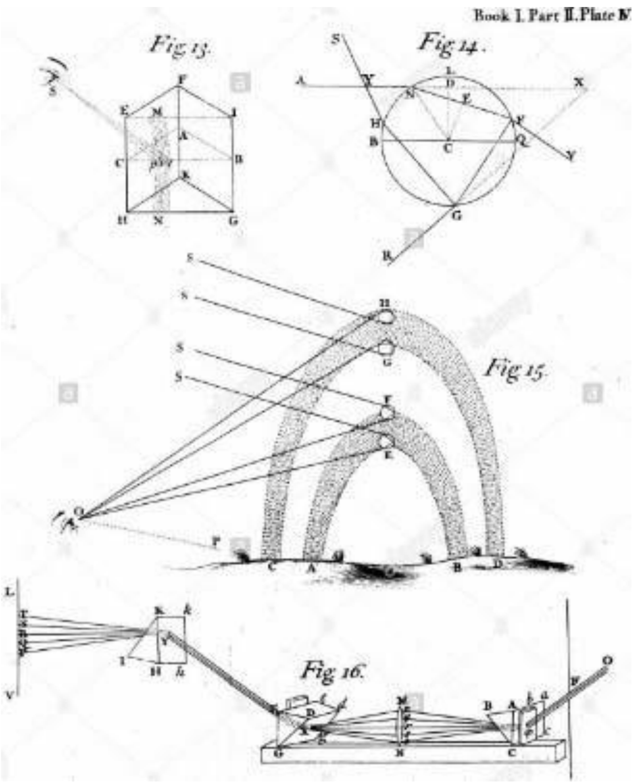


Fig. 9 - The rainbow as explaned by Newton.

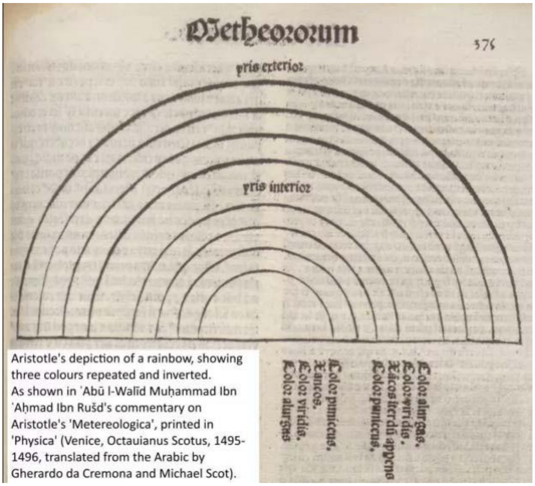


Fig.10 - Aristotle description of rainbow [2].

The theory of colors had many interpreters: from Aristotle to Newton, but especially with Goethe [3], with a more subjective and psychological interpretation, and in the discussion of which he influenced many artists, especially Kandinsky.

Newton, with his interrogative work on Nature, predicted innumerable situations that would result three centuries later in modern theories of Einsteinian gravitation, field theory, particle and nuclear physics. However, to consider that the Newtonian theory was surpassed by our contemporaneity is to go the wrong way. Spectroscopic analysis of the light from distant stars and galaxies and their *redshifts* have proposed the current Big Bang paradigm. However, Newton with his *Queries* propose us new possibilities for an even greater Universe and, according to Giordano Bruno [4] [5], infinite in space-time.

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Lighting Design, Well-being and Educational Buildings

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1. Introduction

In this paper, lighting is discussed as one of the central parameters for improving the learning environment and the students' academic performance. Since the early 70s, many studies have dealt with the influence that the specific features of natural and artificial lighting have on the well-being of students and teachers and on their cognitive performances at school and university during the activities of teaching and learning. In particular, these studies have investigated mood, mental performance, activity, alertness and cognitive functions along with the influence on psycho-physiological related behaviors and learning performances. This is a wide topic of study which ranges, through a variety of educational establishments, from early childhood nurseries and playrooms to university lecture rooms; all these studies focus on the stimulation of students to learn and interact and meanwhile on lowering energy use and maintenance costs.

1.1 The structure of the paper

The section *theoretical background* of this paper presents the recent field studies, which focus on the effects of light in the learning process in educational applications. After that, there is a summary of the main parameters of lighting that allow better *academic performance* and have *psycho-physiological influences*. Then, the paper highlights a *case study* by presenting lighting measurements of a real situation of a elementary school located in Milan. Finally, in the *general discussion* the paper presents and comments the preliminary results and the possible improvements of both natural and artificial lighting.

2. Research scope

The paper aims to draw the state of the art of the research of lighting in educational establishments through an extensive literature review and a comparative case study. The research questions are the following: how can lighting design and research support learning activities, cognitive and mental performance, influence-regulate the circadian rhythm of school occupants and stimulate positive behaviors and mood?

3. Method

The theoretical section clarifies the relationship between light and well-being in educational buildings. The insights from the literature review have been compared to the actual situation of a public elementary school building located in Milan (Italy) where measurements of natural and artificial lighting were performed on-site (11th October 2017 from 10:30 a.m. to 4:30 p.m.). The Illuminance Spectrophotometer CL-500 (Konica Minolta) was used to measure illuminance at eye (E_{eye}) at 1.08 meter from the floor, spectral power distribution (SPD), along with chromatic rendering index (R_a) and correlated color temperature (CCT). The software Color Calculator [1] was used to gather information about the occurred circadian activation. A Luminance-meter LS-100 (Konica Minolta) and a camera Canon Eos 550D equipped with the standard lens (18-55mm) along with Luminance HDR and

HdrScope software were used for calibrating HDR images and extracting Luminance images.

4. Theoretical background about the Impact of Light on Learning

Vision is the preliminary, fundamental function of lighting in educational premises for visual task performances on tables and blackboards. Lighting is also important for safety issues: visual perception of potential hazards, correct navigation of the spaces and visual comfort. These features can be linked to insufficient light (low illuminance) or vice versa to high luminance contrast in the space (wrong lighting distributions) which can cause disability glare, veiling reflections or shadows. Visual discomfort derived from glare should also be avoided to reduce headaches, eyestrain, sore eyes and pains associated with wrong body postures. Apart from this, in the following paragraphs, the paper focuses on the influence of lighting on academic performance, mood and behavior.

4.1 The importance of daylight

Daylight in educational buildings is of overall importance for both academic performances and energy savings. The quality, quantity and the correct distribution of natural lighting inside the space ensure visual performances as well as visual contact with the outside. Specific SPD features (e.g. blue-enriched light) are also ideal for the activation of circadian rhythms. Preliminary studies in 1967 [2] found that high school students in a windowless school were unhappier than those in similar schools with windows. Kueller and Lindsten (1992) [3] discovered that Swedish children had diminished their levels of cortisol when they were located in a windowless school, resulting in reduced concentration and diminished health. In between 1999 and 2003, some studies [4,5] claimed the positive effects of daylight on the academic performances (such as reading and math capabilities) of students in US schools (21.000 participants). Similar results were achieved by an Iranian study on university students [6]: more available daylight was found to improve performance and satisfaction.

4.2 Artificial Lighting and Academic Performances

Recent studies demonstrated that optimized lighting settings, designed specifically for classrooms' activities, can affect academic performances. Higher illuminance and CCT can improve *visual acuity*, *concentration* and *oral reading fluency (ORF)* along with better *comprehension* and *errors reductions* during tests. Barkmann et al. [7] found that, with the Concentrate Lighting Setting (1.060 lx @ 5.800K), students made fewer errors in comparison to the Standard lighting (300 lx @ 4.000K).

Three field studies conducted in the Netherlands by Sleegers et al. (2013) [8] found a positive trend for increased concentration and fewer errors under the experimental condition (focus lighting setting 1.000lx @ 6.500K) against the standard lighting setting (300 lx @ 3.000K to 4.000K). In the study of Mott et al. [9] 84 participants were tested for the focused task under standard lighting settings (500lx @ 3.500K) against optimized lighting (1.000 lx @ 6.500K) in four classrooms with reduced daylight penetration. A better ORF was found in the experimental group with the optimized lighting (assessments in September - January - May).

4.3 Lighting and the Circadian Rhythm

The learning processes occur not only during daytime but also during the sleep. The quality and quantity of sleep have been proved scientifically to be an important factor for students' learning capabilities. Sleep problems, such as insomnia, insufficient amount or interrupted nightly sleep, can cause daytime sleepiness, somnolence, mood disorders [10], learning inefficiency, lower concentration and diminished attention levels along with negative influence on memory. All these factors can result in worst academic performances. Students, who have difficulties in starting the lectures early in the morning, might benefit from an increased lighting exposure (higher CCT and blue-enriched SPD) in the early mornings and a diminished exposure during the evenings. The morning treatment (300 lx of vertical illuminance @ 5.500K) was found to empower students in learning activities through faster cognitive processing speed and better concentration both in short and long-term exposures [11].

4.4 Lighting and Classrooms Behaviors

Studies about the influence of lighting on behaviors are limited in the literature. Few studies state that, by reducing the disturbances of classmates during the lectures, both students and teachers can benefit from a better educational environment. In 1974, students' hyperactivity was found to decrease by using full-spectrum lights vs cool white fluorescents [12]. Another study [13] reported that, through the use of lower CCT and lower lighting levels, a reduction in agitation and disturbance can occur, thus allowing to concentrate better and increase students' academic performances. Similarly, Wessolowski et al. [14] found a reduction in fidgetiness and aggressive behaviors along with a positive influence of prosocial behaviors in the Relax lighting settings (325 lx @ 3.500K). In addition to this, a recent study [15] investigated the correlation between focused non-uniform lighting distribution over the table and the increase in students' concentration and less noise in Danish classrooms. By manipulating brightness variations within the visual environment, focused lighting distribution was found to diminish distractions and to increase focused attention [16].

5. Case Study

The following paragraphs describe the current situation in a specific educational establishment taken as a case study. The aim is to understand, by comparing with the literature review, if the quantity and quality of light, both natural and artificial, are sufficient to allow a good learning situation. The case study is a public elementary school building named "Luigi Cadorna" located in Milan (Italy), Via Carlo Dolci, 5 (Lat. 45.4719907; Long 9.143046).

For the scope of this study, only the classrooms which are located on the first floor (conceived as the worst condition) have been considered. The classroom module comprises both the space of the taught class (learning room) and the space of the corridor. It has a double exposure to natural light: windows are located in the façades and also in the wall dividing the room from the corridor (Figure 1 and Figure 2). The learning rooms present different exposures (South S, West W, Nord/West N/W) according to the building orientation (Figure 1):

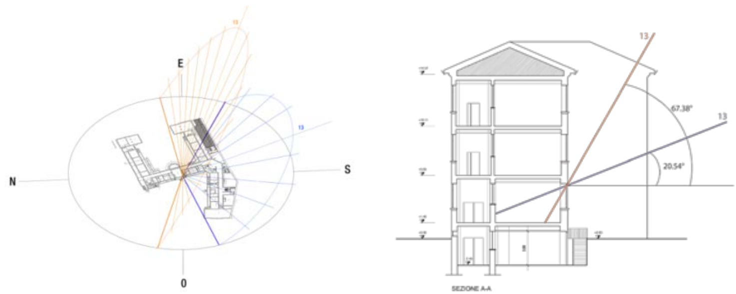

Figure 1 – In Orange Summer Solstice [June 21, 2018]: Duration of the Solar Day: 15 hours and 37 minutes (5:39 a.m. - 9:16 p.m); in blue Winter Solstice [21 December 2017]: Duration of the Solar Day: 8 hours and 38 minutes (8:05 a.m. - 4:43 p.m.)

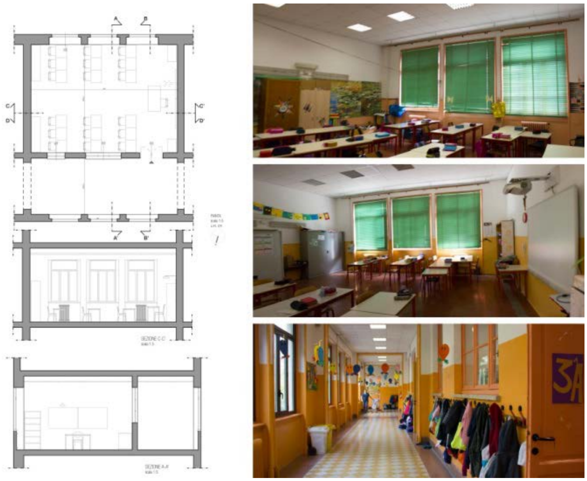

Figure 2 – Example of the classroom module including both class for lessons and the corridor: on the left, plan view and section C-C' and A-A'; on the right, photographic images of the classroom module at the first floor

6. Measurements and simulations

6.1 Found lighting equipment in the classroom modules

The building is equipped with 60x60cm direct lighting fixture with louvres (luminous flux approximately 1.350 lm) and with four T8 fluorescent light sources. The color temperature is 4.000K and R_a 80 (approximated). The lighting fixtures are not dimmable, no dynamic lighting controls are available (intensity levels or tunable CCT or lighting scenes) and no daylight sensors are available to control the artificial lighting output in relation to the natural light. The estimated total power consumption of the single lighting fixture is about 70W and, by considering a yearly working period of 1.800h [17], the annual consumption of the learning room with 8 lighting fixtures is about 1008 KWh. The only available lighting control for natural light is the Venetian blind with manual adjustment.

6.2 Measured working plane Lighting Levels

The measured average working plane illuminances on the students’ desks (0.70 m height) with solely natural lighting (open Venetian blind) in the classroom with double exposure to N/W are comprised between 143 lx (more distant desks from the windows) to 675 lx (nearer desks to the windows). With both artificial and natural light the same points reach 307 lx and 864 lx (compliant with UNI EN 12464-1).
In the classroom module with S orientation, the measured average illuminance on the students’ desks with natural light are comprised between 314 lx (more distant desks from the windows) to 8.200 lx (the nearest desk toward the windows). With both artificial and natural light the same points reach 584 lx and 6.180 lx (due to the high variability of natural light levels). Measurements were taken at 1:00 p.m. the 11th of October 2017 (overcast sky).

1)

2)

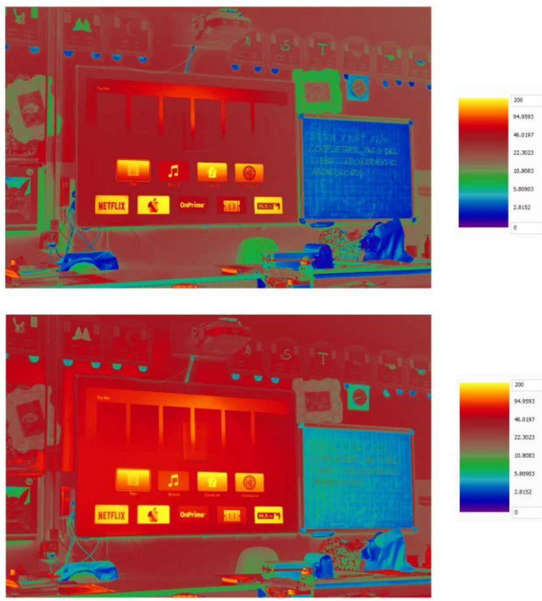

Figure 3 – Example of the digital whiteboard in a classroom: short distance projector on of the digital whiteboard (1) with solely natural light and (2) with natural light and artificial lighting (measurements taken in the NW double exposure learning room from point 2A at 1:00 p.m.)

6.3 Assessment of the lighting contrast on the digital whiteboard

The introduction of interactive and digital whiteboards inside the elementary schools, with the use of short distance projectors on a white surface to show educational content to the students, has changed not only the educational tools for teachers but also the visual tasks for students. In particular, the luminance contrast has to be properly controlled to ensure the optimal vision of the information: from the measurements (1:00 p.m. the 11th of October 2017 - overcast sky) in a sample classroom, it has been evidenced low contrast when the projector and the artificial lighting are turned on, due to the lighting distribution of the lighting fixtures which also cannot be controlled separately from the rest of the luminaires (Figure 3). In addition to this, low luminance contrast could occur with natural light, depending on orientation, sky condition and season.

6.4 Measured Circadian system response

The circadian activation available with natural light was measured at specific points of observation (measurements from 1:00 p.m. to 1:31 p.m. with overcast sky conditions). Figure 4 shows the results of measurements (1:01 p.m.) from the point 2A which is closer to the window, in the double exposed room: E_{eye} 221 lx, CCT 5.212K, R_a 97, estimated circadian system response (Cl) 28%. Figure 5 shows the results of measurements (1:03 p.m.) from the point 1A which is more distant from the window: E_{eye} 176 lx, CCT 4.575K, R_a 97 and Cl 21%. Figure 6 shows the results of measurements (1:31 p.m.) from the point 1A which is more distant from the window (classroom module with S orientation): E_{eye} 463 lx, CCT 4180K, R_a 98 and Cl 39%.

Differently Figure 7 shows the results of measurements (1:28 p.m. from the point 2A which is more distant from the window (classroom module with S orientation): E_{eye} 1080 lx, CCT 4329K, R_a 99 and Cl 54%.

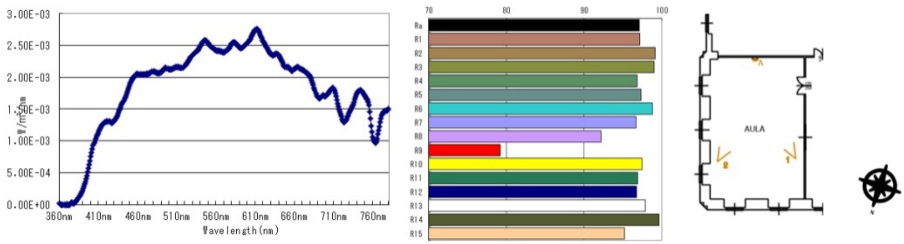

Figure 4 – Measurements of natural light at eye level of sit students at point of view 2A (NW double exposure learning room). From left to right: SPD, R_a, Eyes position in the plan for E_{eye} measurements.

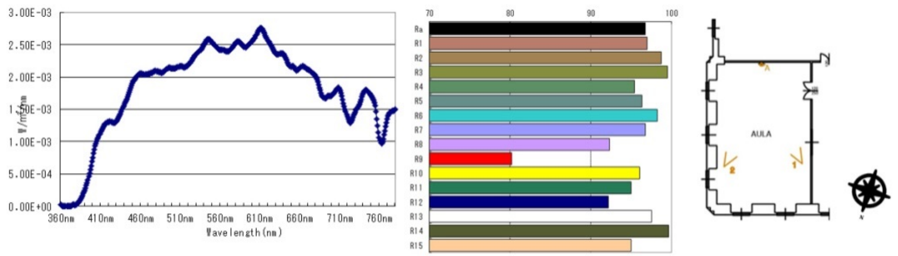

Figure 5 - Measurements of natural light at eye level of sit students at point of view 1A (NW double exposure learning room). From left to right: SPD, R_a, Eyes position in the plan for E_{eye} measurements.

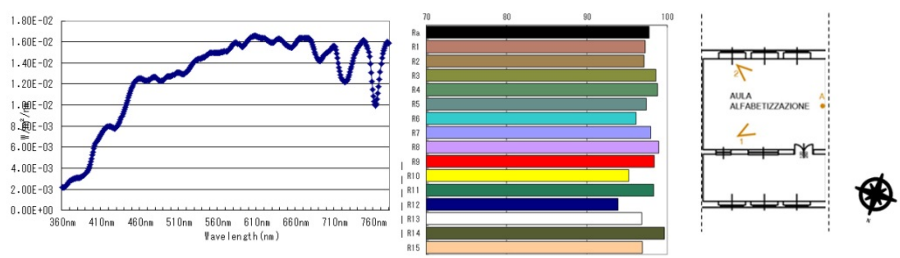

Figure 6 - Measurements of natural light at eye level of sit students at point of view 1A (classroom module with south orientation). From left to right: SPD, R_a, Eyes position in the plan for E_{eye} measurements.

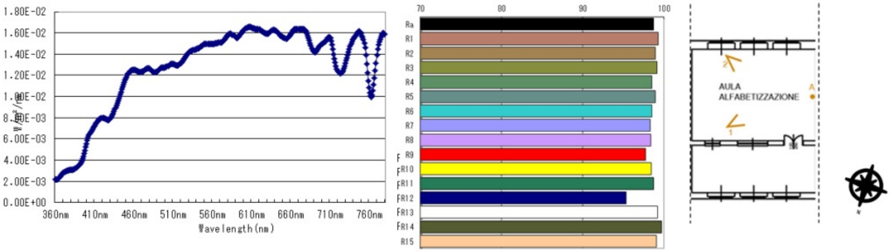

Figure 7 - Measurements of natural light at eye level of sit students at point of view 2A (classroom module with south orientation). From left to right: SPD, R_a, Eyes position in the plan for E_{eye} measurements.

7. General discussion

The results of measurements of the classroom module reveal that, in a specific period of the year (October) and with specific sky conditions (overcast), the amount and quality of light to which students are exposed is compliant with the UNI EN 12464–1 in terms of average maintained illuminance on the desks, when both artificial and natural lighting are available. In relation to the new visual tasks derived by the use of the digital whiteboard, it has been found that natural light and artificial lighting have to be limited in the direction of the whiteboard, through the use of proper shading systems and specific lighting fixture with selected lighting distribution, to ensure a better vision and to balance the contrast rendering factor of the digital whiteboard with the background.

More than this, the assessed lighting levels are not sufficient to enable non-image-forming (NIF) effects of lighting. In particular, even in the most favorable condition, with the E_{eye} measured next to the windows, for a student who is looking at the digital whiteboard in the classroom module oriented toward South at a favorable hour of the day (about 1:00 p.m.), the circadian activation results medium (54%). Compared to this, in the worst periods of the year (winter and autumn, particularly with overcast and intermediate sky) and with the worst sun orientation, it is hypothesized that the circadian system would present extremely low activation. In these conditions, a different lighting strategy is recommended to achieve the circadian activation.

If the literature review describe that the quantity and quality of both natural and artificial light (angular distribution and color of light, intensity and orientation) can influence the cognitive skills and the performance of students, in the case study, neither the natural lighting nor the artificial lighting are designed for well-being and better learning performances. In the analyzed classroom modules, a static condition of CCT of white lighting was found: about 4.000K for the artificial lighting and a range from 4.180K to 5.212K for natural lighting, depending on the specific conditions of sky, period, hour of the day and the position of the observer, if near or far from the windows. Differently, the literature review underlines the importance of using specific lighting recipes which can be dynamically changed both in terms of CCT and intensity of artificial lighting and which can be combined with the natural lighting to support the rhythm of school class activities: in particular, artificial lighting and natural lighting should be able to enhance light levels with a blue-enriched SPD in the morning hours to re-set the circadian rhythm and to support concentrated and stressful studying activities. In addition to this, artificial lighting should also support relaxation and less focused activities through lower intensity and warmer CCT. Furthermore, the lighting design should also focus on the balance between exposure and protection (e.g. avoiding glare and heat) from natural lighting through dynamic lighting systems; these should allow automated adaptation with passive or active systems for a comfortable luminous performance.

8. Further steps

The study presents preliminary contributions for advancing the knowledge about the effects of natural and artificial lighting in students in educational applications. It could be further developed firstly by simulating natural lighting performances throughout the entire course of the year. A second research step is to propose a dynamic lighting strategy in relation to activities and daylight and to perform lighting simulations.

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4. COLOUR AND PHISIOLOGY

Comparison of colour perception in control subjects before and after fitting coloured filters

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1. Introduction

According to the World Health Organisation (WHO) there are 253 million living with vision impairment: 36 million are blind (the corrected visual acuity of the best eye is lower than 1/20) and other 217 million have moderate to severe visual impairment (their corrected visual acuity ranges from 3/10 to 1/20). Moreover, 81% of these people are aged 50 and above but there are also 19 million children. Probably these numbers will grow up due to the ageing of the population and to the related amount of risk of vision impairment due to chronic eye disease [1].
Tinted lenses can be used as an aid: by absorbing both UV rays and blue light, they maximise the use of residual vision, improve visual function, control glare and increase orientation and mobility skills. In particular, they are often prescribed to people with low vision due to pathological conditions: age-related macular degeneration, cataract, retinitis pigmentosa, diabetic retinopathy, cone dystrophy and oculo-cutaneous albinism [2].
A revision of the literature related to this issue shows controversial and equivocal results: many studies report subjective improvement but fail to prove any consistent objective benefit. Anyway, two effects have been established: an increasing in dark adaptation and a worsening of colour vision [2]. Especially the study of Lynch and Brilliant (1984) showed that the application of a CPF®550 filter on subjects with acquired colour loss while performing the City University Test increases the degree of the original defect but also improves dark adaptation as it reduces the retinal illumination [3]. Van de Berg (1990) analysed the application of a red filter on patients with retinitis pigmentosa: he reported that the filter induced patients to make more tritanopic errors compared to without the filter. In the same study he evaluated a CPF®527 filter and discovered that it accelerates the process of dark adaptation with extrafoveal fixation when some rod function was still present [4].
This work aimed to understand if tinted filters modify colour vision when applied on control subjects. The evaluation was made either by using optometric tests and by considering the subjective response to coloured scenes of everyday life.

2. Colour vision

Colour vision is a phenomenon that occurs thanks to physical, physiological and perceptive elements related to the observed scene, to the light wavelength and to the cerebral elaboration of the retinal stimuli [5].
When the light interacts with matter, it can be reflected and/or absorbed and/or refracted or diffused; the appearance of a certain colour depends both on the reflected and refracted light [6]. Only the light in between 380 nm and 760 nm can stimulate the human eye: the so called visible spectrum.
The retina is the first element that works to create the colour perception: it contains rods and cones. The first ones are made up of rhodopsin; this pigment permits the

perception of changes in the level of illuminance. On the other side, there are three types of cones that vary for the different quality of their pigment, the iodopsin: cones S (short) have a peak of absorption at 437 nm and perceive blue-violet light, but they are only the 10% of all the retinal photoreceptors; cones M (medium) absorb yellow-green light, around 533 nm; finally, cones L (long) are sensible to red light with a peak at 564 nm [7].

At the beginning of the XIX century, Thomas Young theorized that every single colour perceived is the combination of three primary colours (red, green and blue-violet) created by three primary receptors. Only after half century the so called trichromatic theory was scientifically verified thank to the experiments of Hermann Von Helmholtz.

In 1878 Edwald Hering proposed the "theory of the opponent processes of colour". According to it, in the cerebral cortex there are three different perceptive canals: one is alternatively sensitive to red and green, the second one to blue and yellow, while the third to black and white. All of them are sensitive to the changes in stimulus of the three cones; moreover, the first two work with an antagonist process for which is impossible to perceive both the stimulating colours in the same place at the same moment. Instead the third, varying the intensity level of the stimulation, sends back a different tone of grey.

These two theories explain phenomena like the existence of complementary colours (red-green and blue-yellow), the vision of afterimages (when one gazes at a coloured point and then, if he looks on a white surface, it will colour of the complementary of the last one) and the perception of pure colours which are not altered by any other colour gradations, but others related to the colour constancy were still not clearly comprehended.

For this reason, in 1968 Edwin Land proposed the Retinex theory which derives from the fusion of the terms *retinal* and *cortex.* It theorizes that a cerebral integration of the information arriving from the retina through different channels, individually sensitive to little portion of the visible spectrum (red-green, blue-yellow and black-white channel), helps to determine the colour and the relative luminance for each single point of the image. With this theory Land went beyond the objective conception of colour perception uniquely related to the wavelength of light that arrives to the retina, introducing a subjective aspect that depends on the illuminance and on the context of the observed scene [6].

2.1. Colour vision anomalies

Colour perception is not always present and regular: when it is partially altered is called dyschromatopsia while if it lacks is called achromatopsia [8]. Dyschromatopsia can be congenital or acquired, respectively when it is already present at birth or if it develops during life.

Congenital anomalies are related to an autosomal recessive inheritance. Red-green anomalies affect more men (8%) than women (0,5%) because genes that codify proteins for M and L cones are on the X chromosome. Since men have a single X chromosome, if it is damaged it is easier that they develop a colour vision deficiency, while women, having two X chromosomes, have a copy of the information on the other chromosome. On the contrary, blue-yellow anomalies

derive from a disfunction of the pigment of S cones which is codified by the 7th chromosome and so they affect people irrespective of gender [9].
Classification of these anomalies was formulated in 1897 by Von Kries and is based on the *trichromatic theory*. When all the types of cones are present and work correctly there is normal trichromacy. Anomalous trichromacy (or anomaly) is when one type of cone does not work correctly and there is a lack of sensitivity to the related colour; dichromacy (or anopia) develops when a type of cone does not work at all and the subject is blind to that colour; finally, monochromatism is the complete blindness to colours that happens when only rods work. Subjects with colour vision defects can be called protan, deutan or tritan when the alteration is related to red, green or blue respectively.
Acquired defects have both different causes and classification. Usually they are consequent to ocular, cerebral and systemic pathologies: cataract, glaucoma, age-related macular degeneration, retinitis pigmentosa, multiple sclerosis, diabetes and other liver pathologies; but also intoxication by drugs [10] or carbon monoxide [5]. Classification was elaborated by Verriest and recognises three groups: the first and the second comprehend red-green anomalies consequent to cone disfunction and optic nerve pathologies respectively, while the third is for blue-yellow anomalies related to choroidal and retinal problems [11].

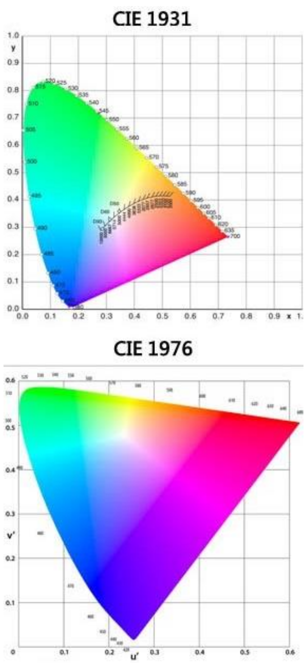

Fig. 1 – Above CIE XYZ diagram and under CIE LUV diagram [13].

2.2. CIE System

It is a colour system that was created in 1931 by the Commission International de l'Eclairage [12] and is based on the idea that each colour can be obtained by the mix of at least three different colours whose characteristics are expressed in terms of the coordinates X, Y and Z. All the colours can be represented in a 3D diagram, but with the introduction of three colorimetric coefficients $x=X/(X-Y+Z)$, $y=Y/(X-Y-Z)$, $z=Z/X-Y-Z$ and given that $x+y+z=1$, colours can be shown on a 2D diagram using one of the couple of coordinates xy (the one commonly used), yz or xz. This graph contains information about the saturation, the dominant wavelength, the complementary colours and the chromatic mix obtainable through additive synthesis.
Afterwards, other diagrams have been studied with the aim of maintaining constant the perceived variations of chromatic differences. For this reason, in 1976 the Commission proposed the CIE LUV diagram (Figure 1) whose trichromatic coordinates derive from the original ones through linear formulas.

2.3. Colour vision tests

It is important to evaluate colour vision in everyday routine controls in order to find people with these anomalies. Until today many tests have been developed but it is possible to group them into three categories: screening tests aim at recognising those people with a colour vision deficiency; diagnosis tests aim to establish type and severity of the anomaly; finally, tests for the assessment of the significance of the colour vision deficiency in a particular vocation, employment or occupation. In particular, all the characteristics of the tests created are based on the confusion axis of the congenital defects which are represented in the CIE diagram.

2.3.1. RP HRR 2002 test

Printed by the Richmond Products, this is the fourth edition of the American Optical HRR test which was created in 1954 by LeGrand Hardy, Gertrude Rand and M. Catherine Rittler, three women whose surname initials gave the name to the test. It is a diagnostic test made up of 24 pseudoisochromatic plates: each of them shows a matrix of points with different dimensions, coloured ones create the image (a circle, a triangle, a cross) while the background ones are grey. These plates are divided into three groups: demonstrative plates (1-4), useful to show how the test work and to establish how to communicate during test performance; screening plates (5-10), three for red-green anomalies and two for blue-yellow ones, that permit to understand if a colour vision deficiency is present or not; diagnostic plates (11-24), to assess the type (protan, deutan, tritan, tetartan) and the severity (low, medium, high) of the deficiency. Plates have been created so that colours of the image and background belong to the same confusion axis: the nearest they are the hardest will be to recognise the image on the corresponding background. In this way errors committed on the first diagnostic tables mean a severe deficiency, indeed colours here are chosen distant from each other, while others at the end show a light anomaly [11].

2.3.2. Lanthony Desaturated D15

From the idea of Farnsworth derived this diagnostic arrangement test which requires the subject to order 15 coloured caps from a fixed one, only relying on his personal colour perception. Colours of caps have been chosen in the Munsell colour system, that is a three-dimensional space in which all colours are represented in terms of Chroma (or saturation) – Hue (or colour) – Value (lightness) [14]. It has the main structure of the Farnsworth D-15 panel test (FD15) but, instead of its Value 5 and Chroma 4, the Lanthony D15d shows a Value of 8 and a Chroma of 2. For this reason, while the FD15 can dichotomize people with severe colour deficiency from those with a normal vision, the D15d distinguishes moderate from severe anomalies and can be used also to analyse acquired colour vision defects.

For the evaluation the examiner uses a sheet representing a circular diagram with the caps numbered from 1 to 15; here he reports the order of caps given by the subject.

There are many diagnosis methods both qualitative or quantitative. In qualitative evaluations, the examiner counts “crossings” (lines which link inverted caps and that pass through the centre of the circle) and compares the parallelism of the lines with the confusion axis in order to understand the severity and the type of the anomaly.

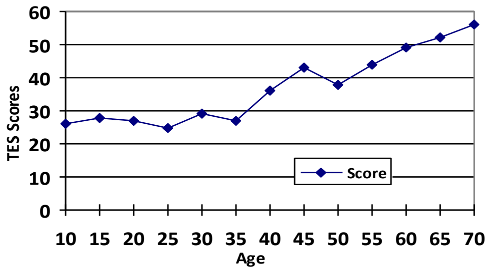

Fig. 2 – TES critical values of the Lanthony Desaturated D15 test: above them a result is pathological with a 95% probability [15].

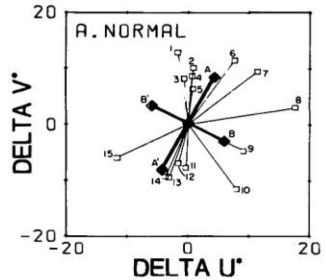

Fig. 3 – Colour difference vectors of a normal arrangement; major and minor radius are highlighted [16].

On the contrary Lanthony's method (1986) is quantitative: it calculates the TES (Total Error Score), the sum of colour differences between each cap and its neighbours in the subject's arrangement, using weights given by the author that refer to the FM100H test. This method comprehends also an age-related classification of the critical values of this parameter (Figure 2): they are less than 30 for people under 40 while over this age the parameter slowly increases. Comparing the result obtained by a subject with these critical values it is possible to understand whether his distribution of caps was pathological or not [15].

Another method was proposed in 1988 by Vingrys and King-Smith; it transposes all the caps in the CIE LUV colour system and creates a system of colour difference vectors that have a common origin and whose 'head' represent the coloured cap (Figure 3). Afterwards, imaging it as a normal mass system in which each cap is connected with the centre through a weightless, rigid bar, the moment of inertia is calculated along the directions with maximum and minimum values, that will be called major and minor radius respectively. Combining these two elements, the method calculates three parameters: the confusion angle, which shows the orientation of the confusion axis and so the type of colour vision defect; the confusion index, which informs about the degree of error relating to a correct arrangement and so the severity of the anomaly, the selectivity index, that gives an idea of the level of polarity or randomness of the arrangement [16].

3. Coloured Filters

A coloured filter is a particular lens that absorbs the radiation depending on its wavelength or its polarization.

These filters can be personalized as spectacles or clip-on; they are produced as lenses with a refractive index of 1.5 and can be both neutral or graduated (monofocal, multifocal or progressive). On specific request an antiglare treatment can be added, but not the hardener one because its deposition could alter the spectrophotometric characteristics of the lens, which are obtained with a bath in a particular solution where it remains until reaches the desired properties.

The transmittance spectrum of these lenses shows as they absorb not only UV rays but also a part of the visible spectrum. For this reason, when applied on the eye, some of the photoreceptors which are sensitive to this part of the spectrum are "under-stimulated" with increasing contrast and vision quality reduction.

They are made for: protection of rods through the reduction of blue light transmittance; glare reduction for generalized absorption of light; increasing visual acuity; reduction of time adaptation to luminance variations; general improvement of visual comfort. They are generally recommended to people with age-related macular degeneration, optic nerve atrophy, retinitis pigmentosa, diabetic retinopathy, achromatopsia, rods or cone S monochromatism, cataract. Visual acuity, contrast sensitivity and visual field are some of the optometric tests used to prescribe these filters but finally the subject chooses the one that gives him more aid and comfort.

Fig. 4 – Zeiss coloured filters: from the bottom to the top, F540 – F560 – F580.

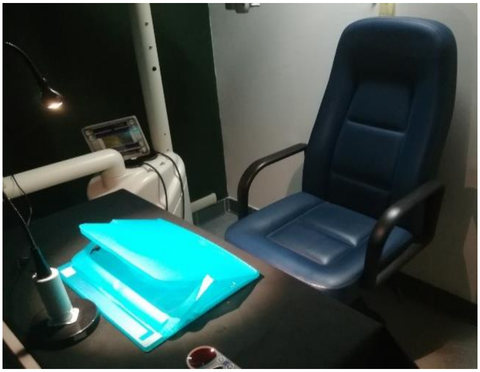

Fig. 5 – Test stand.

In this study three out of nine coloured filters of a kit given by the Zeiss company (Figure 4) were analysed; the name of each one derives from the wavelength for which transmittance level is reduced of 50%: F540 (540 nm), yellow coloured; F560 (560 nm), orange coloured; F580 (580 nm), red coloured. They absorb the part of the spectrum to which cones are more sensitive and so give protection, reduce glare and improve light adaptation.

All of these filters cannot be used both for night and daytime driving and, moreover, they are realised only by medical prescription.

4. Materials and Methods

In this study 69 subjects have been examined, all of them were students and professors of the University of Turin; the group was made up of 26 males and 43 females with and average age of 21.8 (± 2.6) years. Selection criteria have been: absence of ocular pathologies; absence of binocular vision pathologies (amblyopia or strabismus); binocular visual acuity for near distance (40 cm) at least of +0.10 logMAR. All subjects with spectacle compensation, contact lenses or orthokeratology have been accepted. Data taking has been realised in the Optometry laboratory of the University located into the Innovation Centre; the location has always been the same. The space was organised with a table and an armchair, like shown in Figure 5; a black cloth was used to cover the table and there all the instruments were arranged: a lamp, which was the light source for all the tests; a bookrest, which was inclined of nearly 30° to hold the tests.

The exam lasted approximately for 30 minutes and comprehended the analysis of the near visual acuity, the evaluation of colour perception both with two optometric tests (Lanthony desaturated D15 and the RP HRR 2002) and in a subjective way by the observation of an image of a landscape. Every part of the exam was firstly carried out in the subject's habitual condition of vision and afterwards with the fitting of coloured filters.

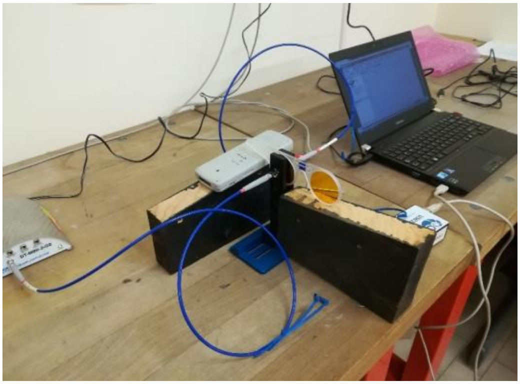

Fig. 6 – Instruments used for the measurement of filters transmittance.

The light source used during the exam was a LED lamp with a power of 2.0 W and a luminous flux of 88 lm, which created a luminance of 1400 lux on the black surface of the table and of 548 lux on the bookrest inclined of 30°.

Each of the three coloured filters that have been used in the exam were measured with a DT-MINI-2-GS lamp and a USB2000+ spectrophotometer and collected data have been examined through Spectrasuite Software (Ocean Optics, Inc.). Instruments used for measurement, provided by the University of Turin, were located at the laboratory of the Physics Department and are shown in Figure 6; initially, after switching off all the sources of light in the ambient, background lighting was measured. Afterwards the intensity of light from 178 to 882 nm that hit and was transmitted by each filter was measured using optic fibres.

4.1 Experimental protocol

Initially the dioptric power of the refractive correction of the subject was measured with a manual lensmeter. Then the person sat on the armchair and his near visual acuity (VA) was evaluated using a chart with LEA Symbols [17] placed at 40 cm on the bookrest inclined so that subject's direction of gaze was perpendicular to the surface of the chart. The test was performed monocularly with the occlusion of the opponent eye with a translucid scoop and subsequently with both eyes opened. The subject had to refer the name of the symbol at the beginning of each row until he reached 0.0 logMAR. Next, he read all the five symbols of a row until he was able to recognise them; it was noted the VA of the last row in which he recognised at least 3 out of 5 symbols.

Then Lanthony Desaturated D15 test (D15DS) was performed; the subject was asked to reorder 15 caps placed randomly on the table in a sequence; the reference cap was positioned at the left side of the holder and every time he had to choose which one of the group seemed to have the most similar hue. Execution time was limited to two minutes but there were no limits in changing caps order. During the test performance the subject had to wear a pair of white gloves so that he could touch caps without altering the chromatic characteristics of their pigmentation.

Next the HRR 2002 of the Richmond Products (HRR) test was executed: it was located on the bookrest and the subject, wearing the white gloves, told the name of each of the symbols that he saw on the page and at the same time pointed with his finger the place where they were located. The performance started with demonstrative table and comprehended all the 24 tables; no time limits were imposed but he was forced to say quickly if he saw any symbol.


Fig. 7 – Image shown to analyse changes in the level of luminosity of colours with filter anteposition.

These parts of the exam were performed once in the habitual condition of vision of the subject and afterwards with the fitting of the three filters in sequence: F540, then F560 and finally F580.
The last part of the exam consisted in the evaluation of the alteration of colour perception induced by filters. The image of a landscape (Figure 7), printed on a plastic support of 30×45 cm, was placed on the bookrest. The subject had 10 seconds to observe it with his/her habitual condition of vision and then had to wear the filter and refer if the luminosity of four coloured details of the image (a green sun blind, a red ship, the prow of a light blue ship and a yellow line on the ship in the first place) was changed and also how much (a few, medium, a lot).

5. Data Analysis

5.1. Analysis of transmittance of filters

Transmittance, expressed as a percentage, was calculated as $T = (I_t / I_i) * 100$, where I_t and I_i are the intensity of light transmitted by the filter and incident on its surface, respectively. The values obtained are represented in Figure 8: they show agreement with those provided by the producing company on its technical sheet [18].

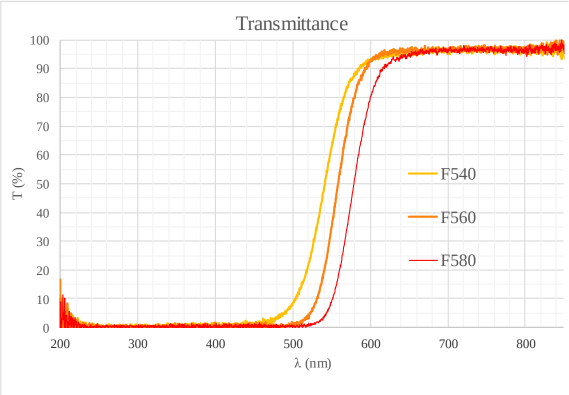

Fig. 8 – Trend of transmittance of each one of the analysed filters.

5.2. Analysis of results of tests for colour perception

For this analysis, parameters were calculated both for the condition of vision without filters (NAT) and with the fitting of filters (F540-F560-F580). For each one the procedure was the same: initially a histogram was constructed to evaluate if the data distribution was normal or not and then mean value and standard deviation were calculated. Then the statistical significance of the differences through different conditions was evaluated with one-way ANOVA for correlated samples followed by a Tukey test when the null hypothesis (H_0: means do not differ) was rejected. In particular, this test analysed both variation between all the filters and the habitual condition of view and also between various filters (F540-F560, F560-F580, F540-F580).

5.2.1. D15DS Test

Collected data have been analysed firstly with Lanthony P. method and then with Vingrys and King-Smith one by using the Torok B. calculation system (2013) [19].

5.2.1.1. Lanthony method

TES value of each subject was compared to the critical value with a confidence level of 5% (27 for an age range from 20 to 24): people with a higher value, probably having an altered colour perception, were excluded from the study. The new sample was made up 61 subjects: 22 of them were men and 39 women; mean age was (21.9 ± 2.7) years while binocular near visual acuity was (-0.18 ± 0.10) logMAR.

5.2.1.2. Vingrys and King-Smith method

After having obtained minor and major radius confusion angle (Ang), selectivity index (S-index) and confusion index (C-index) were calculated both for the condition without the filter (NAT) and with F540, F560 and F580.
ANOVA showed that all differences of mean values relating to C-index and S-index were significant (p<0,001); instead for the parameter Ang any variation was not significant. Moreover, Tukey test for C-index referred a high significance (p<0,01) for the comparison of vision through filters with habitual compensation while changes induced by various filters were not significant. Instead, S-index changed always significantly (p<0,01) both when comparing filters with normal condition of view and filters between each other.

5.2.2. HRR Test

Considering only the diagnostic table, the number of errors committed (symbols not seen) by each subject was counted to calculate two parameters:

Table	Weight	Table	Weight
11	0,51	16	1,02
12	0,64	17	1,15
13	0,64	18	1,28
14	0,77	19	1,40
15	0,90	20	1,53

Tab. 1 – Number of tables and corresponding weights; these values progressively increase as difficulty in recognising symbols decreases inversely [20].

- Normalized Total (TOT_{NORM} = the ratio of the total of errors committed on the total of possible cases) that varies from 0 when no errors were committed to 1 when the maximum number of them was committed;
- Weighted Total (TOT_{PES}), sum of the number of errors committed (with a value of 1) multiplied for the “weight” of the table in which they were committed; in particular, this parameter has been

considered only for the tables which evaluated protan and deutan anomalies and weights were found in an article of Bailey et al. (Table 1) [20].

These have been calculated both for vision without (NAT) and with filters (F540-F560-F580) and relatively to four conditions for anomaly of perception of red (Protan), green (Deutan), blue (Tritan) and yellow (Tetartan).

In the ANOVA the null hypothesis of no variation of mean values has been rejected both for TOT_{NORM} and TOT_{PES} with a probability of $p<0,001$. The Tukey test showed that the variations of the parameter TOT_{NORM} are significant ($p<0,01$) both for the Deutan and Protan anomalies and also both for the Tritan and Tetartan with two exceptions. The first in the comparison F540-NAT of the Protan condition, where significance was $p<0,05$; the second for the same comparison of Deutan and Tritan anomalies where the difference was not significant. Even the parameter TOT_{PES}, analysed only for the conditions Protan and Deutan, has changed significantly ($p<0,01$ apart from the comparison F540-NAT of the Protan anomaly, $p<0,05$).

5.3. Analysis of answers to the observation of the image

Perceived luminosity						
Reduced			Unchanged	Increased		
A lot	Medium	A few	-	A few	Medium	A lot
-3	-2	-1	0	+1	+2	+3

Tab. 2 – Numerical values attributed to each one of the possible answers of the questionnaire.

The questionnaire has been presented to 45 of the 61 subjects. For the analysis, each one of the possible answers was associated with a numerical value, according to the criterion showed in table 2; then all the steps described above have been applied in relation to the three conditions of exam (F540-F560-F580) and to each colour of the details of the image (yellow, blue, red and green).

The type of distribution shown by the histograms was always normal (Figure 9) and the hypothesis H_0 of the ANOVA has always been rejected. Tukey tests for all the four coloured details were significant ($p<0,01$) apart for the comparison F540-F560 of yellow and red in which there were no significance.

6. Discussion

From the results of the analysis of collected data it is possible to say that coloured filters, usually applied on people with particular ocular pathologies to increase quality of vision, if applied on control subjects induce an alteration of the quality of colour perception. In particular, this is also confirmed by the high level of significance (5% and 1%) of the statistical tests executed in the analysis. The random variations of the parameter Ang and the increment of the parameters S-index and C-index of the Lanthony desaturated D15 test passing from the normal condition of vision to the fitting of filters permit to understand two elements: firstly, the anomaly of induced perception cannot be univocally categorized as protan, deutan, tritan or tetartan; moreover, higher is the filter cutting frequency, more is the level of confusion of the person in distinguishing colours and in ordering test caps.

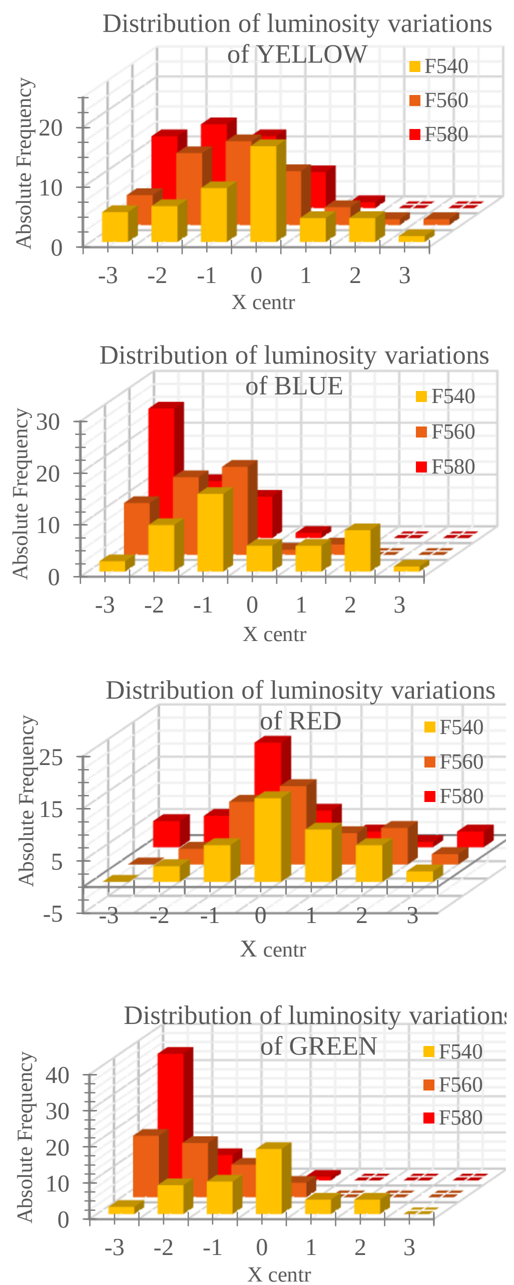

Fig. 9 – Histograms for the distribution of answers to the questionnaire relative to variations of luminosity of the details of the image, from the top to the bottom: yellow, blue, red and green.

RP HRR Test confirms what has emerged from the D15DS: the vision of both red and green worsens with filters F540 – F560 – F580 (4% - 11% - 23% and 2% - 10% - 22% respectively). Blue colour vision worsens of 2% and 7% with filters F540 and F560 and as much as 37% with filter F580. Anyway, the colour that has been penalized mostly is yellow: indeed, worsening has been of 49%, 56% and 78% with the filters in succession.
Analysis of data relative to the observation of the image confirms general changes. Percentage of variation of the means of the answers have been calculated for each colour: the most penalizing filter is the F580 as subjects have perceived a reduction of luminosity of 24% for the red colour, 56% for the yellow colour, 78% for the blue colour and of 90% for the green colour. In opposition, the less penalising filter has been the F540 as it reduced of 11%, 14%, 16% the luminosity of the blue, green and yellow colour respectively while for the red colour luminosity has been enhanced of 13%.

7. Conclusions

This study aimed to understand if coloured filters induce alteration of colour perception when applied on subjects. Even if these filters are normally used for people with some ocular pathologies, here the examination has been executed with control subjects due to the difficulty of finding a sample that was large enough for a statistical analysis. According to the results obtained it is possible to say that colours seen through these filters are partially altered.

It is then very important that in exam routine, apart from tests that evaluate visual acuity and contrast sensitivity, a group of tests that analyse colour perception is added. In this study Lanthony Desaturated D15 and RP HRR 2002 test have been used; they permit to evaluate both the degree of severity and the type of anomaly and are also very easy to understand and quick to be executed.

Furthermore, when there is more than one filter that in a specific condition can help the subject to improve his vision conditions, it is important to choose the filter that alters less the vision of colours: in this case F540 and then F560 and F580.

For the future, it could be important to repeat the study with a sample comprising people with pathologies in order to understand if, according to the results obtained in this study, the prescription of these filters can be improved. In addition, other filters that are commercially available can be studied in relation to colour perception, contrast sensibility and visual acuity.

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5. Colour and Restoration

Potentialities of reflectance hyperspectral imaging technique in the field of architecture

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1. Introduction

In the architectural field, the theme of colour in its broadest sense is immediately linked to the discipline of urban restoration. In fact, among the fundamental themes of urban restoration (in addition to the correct interpretation of the constructive tradition of the place, the choice of materials and the most appropriate technologies with which to operate maintenance and renovation of buildings and facades), there is the decoration topic that is expressed through the skin of the existing building and in particular by its colour. The colour of the city is in fact a witness to a dynamic process that derives from changes in fashion and taste and therefore involves a careful assessment of the historical evolution of the urban environment. Furthermore, in architecture, analysing colour signifies knowing the history and life of the artefact. It means having a perception of the place, knowing the 'compositional grammar' of the building and the processes that make up urban architecture [1]. Therefore, restoring colour includes the totality of art restoration, from its first definition to its smallest and most complex compositional details [1].

But the definition of colour is a very complex matter and its perception has an extremely subjective nature that often gives rise to multiple interpretations and evaluations. For this reason, over the years, methodologies for colour accounting have been developed and consolidated to analyse and interpret colour in the most objective way, taking into account its most intrinsic definition:

"... color defines simultaneously a perception and a chromatic matter. Its nature is complex and hermetic: in a material sense it is equivalent to a given pigment; in the physical sense, it corresponds to an electromagnetic band defined in the light spectrum; in a physiological sense it depends on the genetics of the receptors of the organ of sight; in the perceptive sense, it is disposed as a subjective, relative and connected sensation to all the above mentioned phenomena; in the artistic sense it is the material expression of the form; in symbolic terms it is the sign language codified ..." [2]

In the architectural field, more methodologies have been stratified for the urban colour analysis, moving from the more objective (scientific) to the more subjective (interpretative) ones.

One of the main tools for the identification of the elementary cells of the "chromatic landscape" is given by the analysis that relates the "perceived colour" with a coded chromatic class, using distinct detection systems in technical reports [3].

These analyses can be divided into two main categories:

a) instrumental type, with filter based (tristimulus colorimeter) or grating based (spectrophotometer or spectrum-colorimeter) devices, in which the colour definition is made by using acquiring measurements with the subsequent mathematical processing of the data to obtain the colour identification by means of coordinates conventionally assumed (e.g. CIE-L*a*b* parameters) in specific colour spaces [4];

b) comparative "fast" type, i.e. using "colour cards" (standardised methods, covered by patents and identified by acronyms, such as: ACC, NCC, NCS, etc.). These are technical systems derived from scientific data models that allow to define and code in a logical sequence every possible detected shade [4].

However, both approaches present some constrains when “city colour plans” are considered. In fact, the instrumental type methods use contact-based devices that means the instrument has to be in contact with the studied surface; while the second methodology depends on the ‘operator judgement’ which does not guarantee a reliable and ‘objective’ results.

A consolidated imaging methodology, named reflectance hyperspectral imaging (HSI) technique, is here proposed as a brand new possible system for overcoming some of the problems faced with the previous two approaches. HSI, indeed, was first introduced in the 1980s in the field of remote sensing, and it revolutionised scientific research on earth surface investigations [5]. HSI is a sophisticated technology that allows for the simultaneous capture of hundreds of reflectographic images of a given scene, acquired on contiguous narrow bands over an extended spectroscopic interval, typically covering the visible and the near infrared regions. Thus, hyperspectral data contain exhaustive spectroscopic information, usable to extract highly-resolved reflectance spectra from each pixel of the image. This makes it possible to attain mapping and identification of materials throughout the imaged area.

The potentialities of HSI technology were partially counteracted by the complexity and costs of instrumentation, the need for software and hardware resources to store and process big-size data-cubes and, the availability of skilled staff to make the final data fully exploitable. In addition, most of the HSI systems were cumbersome and not designed for working outdoors on tripods.

In order to overcome some of these limitations and to further extend the possibility of applications of HSI to indoor and outdoor objects, including large-size wall paintings, ceilings, decorative elements and inscriptions, and facades, a new hyperspectral camera has been recently developed by SPECIM, Spectral Imaging Ltd. (Oulu, Finland) that features compactness, lightness and it is easy to use (Fig. 1). The advantages of this device come in the forms of its reduced dimensions, diminished weight, and a user-friendly interface that make this camera much more portable, manageable and affordable than conventional HSI instrumentation. It can be mounted on a tripod and its optical module allows for imaging of different size areas by varying the working distance from short-distance (tens of cm) to long distances (tens of meters) with different spatial resolutions [6].

The first applications of this new compact and portable HSI camera in the context of examination of building facades are reported together to the pros and cons of using this equipment in the colour analysis in “city colour plan” application field.

Fig. 1 – Specim IQ camera during the acquisition of the data in the 1st May square in Brozzi. Upper-left corner: display of the camera with the scene under investigation.

2. Specim IQ camera: technical information

The Specim IQ has been designed to provide a full hyperspectral tool with required features for making hyperspectral imaging possible on different kind of environments [6-8]. It differs from other hyperspectral cameras on the market by integrating the hyperspectral sensor with additional colour cameras, replaceable data storage and batteries, data acquisition and processing electronics, and an optimised operating system and user interface into a single portable housing. The integrated colour cameras support the spectral camera usage by making it possible to direct and point the camera with standard viewfinder image as well as adjust the manual focus of the spectral camera with a normal camera image. By removing the need for additional computers, cabling, power supplies and software, it enables the users to exploit this novel technology in an easy and straightforward way. The rechargeable batteries and standard 32 GB SD memory card for the image data allow approximately 100 measurements to be made with camera without the need to recharge or change the storage media. The operating system is designed in a way that it will guide the user to consider the necessary camera adjustment and data quality validations, without a need to go into details of the hyperspectral imaging technology details. The target on the system design has been to enable users, not familiar with hyperspectral imaging, to successfully start using it in their applications.

The hyperspectral data acquisition with Specim IQ can be made both outdoor and indoor conditions, with Sun light or artificial, broadband illumination. In addition to the Specim IQ and possible illumination, a reflectance reference targets are needed to correct the effect of the illumination and ambient environment effect from the data,

and make the measurements made in different conditions comparable with each other's. Like majority of the hyperspectral cameras, the hyperspectral image is acquired by making a line-scan over the target area. The camera is designed in a way the image scanning is performed with internal mechanisms. Due to image collection by scanning, the process takes in normal conditions from seconds upwards, so it is recommended to use Specim IQ with a standard tripod.
The camera visualises the hyperspectral data immediately after the measurements and the user has possibility to add metadata to the measurement. It is also possible to use the bundled Specim IQ Studio software to create material identification models for the hyperspectral data. These can be installed as applications to the Specim IQ, and when operating the camera with an application, the camera will also process the data and provide the processing results visualisation for the user. In addition to the bundled software, the hyperspectral image data format is compatible with majority of the other hyperspectral data processing software's available in the market.
The Specim IQ covers the 400 – 1000 nm spectral range and provides 7 nm spectral resolution with 3.5 nm spectral sampling – suitable for majority of the materials having spectral response in this wavelength range. The resulting image from Specim IQ is 512 x 512 pixels, with all the pixels containing 204 spectral samples. The camera saves both unprocessed and processed data and the single measurement is approximately 300 MB.

3. How to measure the "city colour plan" with traditional methods: pros and cons

In this chapter, the advantages and disadvantages of the two methods for measuring the colour of a "landscape" or a "city colour plan" reported in the Introduction section are discussed more in detail [1].
The instrumental methods use portable spectrophotometers, which are designed to accurately measure the colour of different type of materials and supports, ranging from paper, paints, plastics, textiles, etc. Generally, they provide absolute and differential data for the various colorimetric systems/spaces.
As for the colour measurements by using spectrophotometers, the problems found in the architectural field can be listed as follows:

1. colour measurements on an inhomogeneous surface; it is easily detectable a different colour from the one perceived;
2. difficulty in detecting colours on glossy or mirrored surfaces;
3. impossibility to directly measure the colour of part of the building not directly accessible;
4. colour measurements on small surfaces (approx. 1 cm in diameter), which means that if the area under measurement is not carefully chosen it may not represent the whole surface hue and the perceived colour.

Usually, when these problems arise, they can be overcome if the definition of the colour is carried out posthumously with colour selection using digital methods on the screen of the computer and then performing the colour check by means of the "remote comparison" on site with colour card sets. However, this practice, if carried out by an untrained and inexpert operator, can cause important errors in the colour determination.

The second method, on the other hand, is faster than the first one and is done through the visual comparison between the studied masonry and a colour card set, which identifies a series of shades that generally correspond to the colours of the available paints.
For this type of methodology, the problems encountered can be listed as follows:

1. different colour values due to different colour perception caused by different atmospheric conditions of light during the year;
2. different colour values due to varying weather conditions during the same day;
3. different colour values due to the alteration of the chromatic perception caused by the direct irradiation of the sun's rays on the area to be detected;
4. impossibility to directly measure the hue of a part of the building because it cannot be directly reached.

Generally, when these problems arise, the following solutions are adopted: the detection of colours is carried out during one season, the spring, as the solar irradiation is more homogeneous and is carried out during overcast days (early in the morning) as the absence of direct irradiation confers uniformity to the perceived colours; where there is no possibility of direct colour detection, this is carried out posthumously with colour definition using digital on-screen methods and subsequently the verification of colours by means of the "remote comparison" on site with the chosen colour cards set. Since both methods have important advantages and weaknesses, a mixed method is often chosen to allow colour detection as objective as possible. When it comes to colour in the field of urban restoration it has to be noted that fronts to be detected often extend for kilometres. This problem represents the biggest obstacle for any operator who is preparing to draw up a “colour plan” [3].
The need to define a more scientific, objective and fast analytical methodology for this type of colour measurement seems to be evident, which must necessarily include the spectroscopic and colorimetric analysis of the totality of the buildings’ facades and not of portions of them.

4. Case studies: results and discussion

The decision to use the Specim IQ camera to measure the colour in “city colour plan” project took place having in mind the basic problems mentioned above. This camera was tested in the main square (1st May square) of the minor historic centre of Brozzi in Florence (Fig. 2); the small town in fact does not have particular historical-artistic relevance by looking at each single building (with the exception of some occurrences), but the whole place is one of the typical hamlets on the Italian territory. It was therefore considered appropriate to take this case as an example.
In order to have a more complete picture on the potentialities of the spectroscopic camera applied to this type of analysis it was decided to choose a rain-free day without any particular responses to lighting conditions. On the other hand, the survey methodology was chosen with greater accuracy. Different types of fronts (buildings’ facades) were chosen with different day lighting: direct lighting and indirect lighting.

Fig. 2 – a portion of the 1st May square in Brozzi.

In addition, several scans were carried out both at close range (single front/facade) and at long distance, or urban distance, (several fronts/facades) in order to evaluate the response of the camera to the colour calculation. A couple of case studies are reported below.

Fig. 3 – the acquired scene with the reflectance spectrum of the selected spot in the image (the white reference target in the bottom-right part of the image).

The first acquisition was taken at a close distance and the region of interest (ROI) included two terraced-houses. The screen shot of the acquisition is reported in figure

3 with the reflectance spectrum of the white reference used to calibrate the hyperspectral data. In the following figures (Figs. 4 and 5) the spectral information on the green window shutters of the white house in the centre of the ROI of the acquisition is considered (Fig. 4). By using the spectral angle mapper (SAM) algorithm, included in the IQ software, it was possible to define the pixels having similar spectral shape than the one chosen as reference (Fig. 5). The perfect match was among the three green shutters of that house, as expected, while the green curtain outside the main door of the house on the right and its green shutters were not selected by SAM algorithm (tolerance 0.9900). It means that these latter objects were painted with a different paint or in a different hue tone than the former. This information was also confirmed by the colorimetric values calculated starting from the reflectance spectra extracted from each selected pixel of the ROI. The colorimetric values were calculated for the illuminant D65 and standard observer CIE1931 (2°) following the *Commission Internationale de l'Eclairage* (CIE) recommendations [4]. The chromatic parameters L*, a* and b* for some designated pixels of the scene are reported in table 1. From these data, it was possible to associate the colour appearance of the objects in the ROI, their spectral shapes, and their CIE colorimetric values in an unambiguous way. As a result, the three spots from the green shutters of the white house showed approximately the same values, which differed from the other two by lightness (L*, point 4) and chroma (a* and b*, points 4 and 5). Specifically, point 5 exhibited lower values for the three parameters, thus resulting darker and less saturated than the spots 1-3; while point 4 presented almost the same L*, a stronger saturation for the green hue (a*), and a lower value for b*. Those data defined a drift towards colder hue (b*<0), moving from yellowish to bluish tone.

Fig. 4 – the acquired scene with the market pixel on the green window shutter (in the centre of the ROI) and its reflectance spectrum used as reference for the SAM algorithm.

Fig. 5 – the pixels having same spectral features in the ROI of the image after having run the SAM algorithm (1-5 points' description as reported in table 1).

	Description of the selected pixel	L*	a*	b*
1	Shutter first floor - SAM reference point	47.8	-22.3	13.1
2	Shutter ground floor	48.7	-23.2	13.6
3	Shutter first floor	47.7	-22.6	13.6
4	Green curtain main door	42.4	-37.5	-4.7
5	Shutter above the main door point 4	38.9	-4	-3

Tab. 1 - L*, a* and b* chromatic values for the selected pixels in the recorded scene.

The second data set was acquired on the other side of the square and at longer distance than the first one, in order to image more terraced-houses in the same registration. Moreover, this time the front of the houses was under the sunrays (Fig. 6).

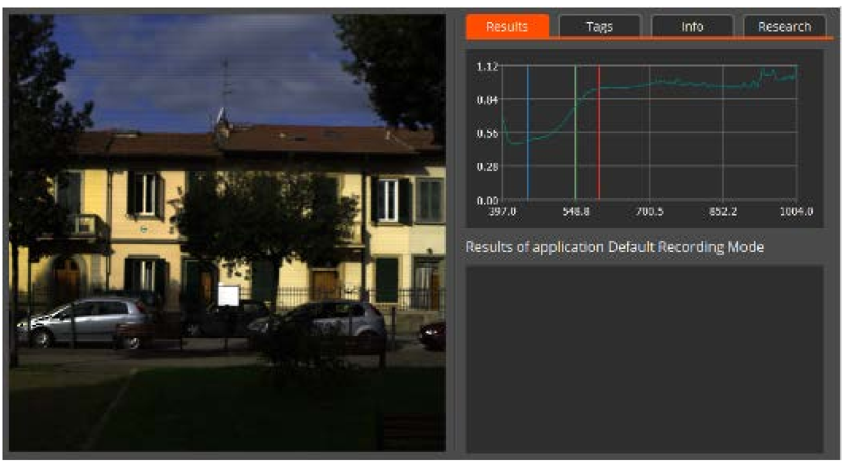

Fig. 6 – the acquired scene with the white reference target in the centre of the image and the pixel at the first floor of the second house from left selected for running SAM algorithm.

Following the same methodological procedure as the first case, it was tested the ability of the system to detect small differences in tones of the same hue used to paint the front of the terraced-houses.
The SAM algorithm made it possible to select the pixels of the façade of the second house from left having similar spectral shape than the one chosen as reference (Fig. 6). This time the tolerance of the SAM was very high (0.9995), close to the maximum value possible (1.0). Despite this constrain, most of the façade pixels of this house were grouped together. One of the outside spots (point 2, Fig. 7), which was not included by SAM in the similarity group (point 1, Fig. 7), showed, however, almost the same colorimetric values than the reference spot, as reported in table 2. This means that the chosen tolerance was too strict to group all the façade pixels or that the texture of the wall was not perfectly homogenous under the direct sun illumination. The third spot was on the same wall but in a shaded area: here the measured colour was different from the other parts of the wall, as expected. However, starting from the reflectance spectra it could be possible to overcome this problem if the whole house façade needs to be represented with the same hue.

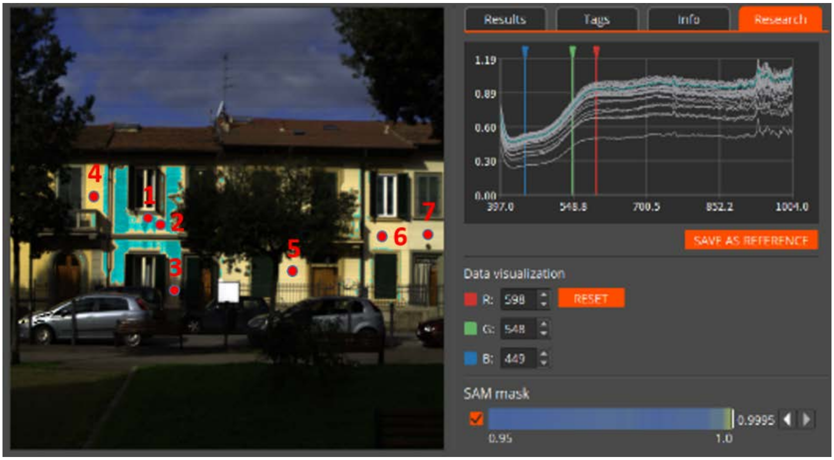

Fig. 7 – the pixels having same spectral features in the ROI of the image after having run the SAM algorithm (1-7 points' description as reported in table 2).

	Description of the selected pixel	L*	a*	b*
1	Wall 2nd house from left below window first floor - SAM reference point	91	6.2	26.2
2	Close to point 1 not included in SAM	90.3	5.9	24.9
3	Wall 2nd house from ground floor in the shade	48.5	3.6	9.8
4	Wall 1st house from left first floor	91.8	5.6	37.5
5	Wall 3rd house from left ground floor	93.8	3.6	22.1
6	Wall 3rd house from left first floor	94.5	3.9	20.8
7	Wall 4th house from left first floor	92.2	1.9	16.1

Tab. 2 - L*, a* and b* chromatic values for the selected pixels in the recorded scene.

The yellowish colours of the other three houses showed small differences in spectral behaviour among them, which produced a diverse chromatic perception on the viewers, as confirmed by the colorimetric values calculated from the spectra (table 2).

All the tints have the same lightness (L*) but diverse saturation values for the yellow hue (b*), which explains the fact that they were not grouped together by the previous SAM process (Fig. 7).

5. Final considerations

The results obtained by using the Specim IQ camera are encouraging because effectively through a well-performed calibration of the white it was possible to determine that the acquired spectroscopic data were homogeneous and consistent when acquired at both close and long distances with direct and indirect lighting. The problems presented were relatively few: in fact it was only necessary to make more scans at different integration times in order to find the correct exposure time for house fronts exposed to direct light.

The scanning times (from few seconds up to a couple of minutes) are low when compared to the type of classical colorimetric approaches mentioned at the beginning of the paper and the results are infinitely more objective when compared to the method with colour chart and / or by using a contact spectrophotometer.

It is therefore possible to summarise the points of merit and the problems encountered in this first application of the hyperspectral camera on the study of the hues of urban fronts.

Points of merit:

- objective analysis of the all-encompassing colour of the front;
- possibility to carry out the survey with both direct and indirect lighting;
- possibility of a faster objective measurement than before;
- possibility of post-analysis of data on a computer without the need for further on-site campaigns.

Issues:

- need to perform more scanning to calibrate the room on fronts with direct lighting;
- need to expand the optical cone of the camera (if there is not enough space from the point of grip to the analysed front).

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Picasso's "Science and Charity" and its three oil sketches: a comparison of their hues through their chromatic values

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1. Introduction

As reported by Gage at the beginning of the introduction of his book "Color in Art" [1], "Colour is implicated in physics, in chemistry, in physiology and psychology, as well as in language and philosophy; yet it is visual art alone that has engaged simultaneously with most or all of these branches of knowledge and experience …". Furthermore, in the same section he ended with "... colour is primarily a psychological phenomenon. Hence, the issues raised are unlikely to be resolved, but instead will be successively reinterpreted and exemplified through the creative ingenuity of artists.". The link between the colour as a psychological phenomenon and the way artists applied their creative ingenuity has been explored and discerned in many works and dissertations by art historians, critics, and artists themselves [2-6]. However, often the considerations included in these treatises are not based on scientific data and measurements. A new approach on this topic could merge the visual approach by expert professionals in the field, such as painting conservators, with the measured colorimetric values calculated starting from the reflectance spectra of the selected investigated spots [7].
This idea was applied to the chromatic and colorimetric analysis of Picasso's (1881-1973) paintings of the Museu Picasso in Barcelona (MPB), since, among the modern painters, he turned from a subdued chromatism to brilliantly varied palettes in the course of his career [1]. The study of some of the most important paintings by Picasso at MPB presented in this paper was carried out in the framework of an inter-institutional research project (ProMeSA) aimed to gain an insight into the failure mechanisms of modern and contemporary paintings [8].
One of the most representative paintings by Picasso of his formative years, "Science and Charity" (Ciencia y Caridad, 1897, size 197.0 cm x 249.5 cm, inv. number MPB110.046), which is one of his significant works in the permanent collection of MPB, has been recently restored. Within the ProMeSA project several documentation and analytical methodologies were used to study the materials and techniques used by the artist. This impressive oil painting on canvas, indeed, is considered his early career highest experience that marked the accomplishment of his academic art education in Spain at the end of the 19th century.
At the same time, MPB has three small oil paintings on different supports (1896-97), together with a watercolour on paper, that are considered the preparatory sketches of "Science and Charity" and are displayed next to the big canvas. These three sketches show differences in the organization of the scene and in the hues used by Picasso in depicting the same characters and the objects reported in the scene.

Starting from a visual inspection of the different colours of the four paintings used by the young Picasso to stylistically structure them, it was decided to select ten spots (area with a diameter of 3 mm) on the same areas of each painting to be measured by using a spectrocolorimeter (Figs. 1-4). In this way, it was the intention of the authors to find any associations among the measured colorimetric values, the chromatic painting balance, and the colour perception of MPB conservators of the painted scenes --the painting and the three oil sketches-- with the aim to better understand their conditions.

2. "Science and Charity" painting and its sketches

At the end of 1896 and beginning of 1897, Picasso drew the painting "Science and Charity" (Fig. 1). Probably, this was the most ambitious work done by the young artist [9]. The choice of the topic was not unintentional; the human dimension of the disease had influenced him since the death of his sister Conchita (who died in January 1895) and, on the other hand, he brought real life and social issues in the depicted scene. Furthermore, with this painting, Picasso (guided by his father), joined the Social Realism movement, which at that time was at the peak of popularity in Europe. The origin of the hospital theme in Spanish painting can be traced to 1889 when Luis Jiménez Aranda won the gold medal at the Spanish Pavilion at the Universal exhibition in Paris with "The Doctor's Visit" among other artists who also painted similar subjects.

Fig. 1 - painting "Science and Charity" (MPB 110046) with reported the investigated spots.

In May of 1897, this large oil painting on canvas was exhibited in Madrid at the 16th Fine Arts General Exhibition, where it was awarded. Some months later it was sent to Málaga in order to participate in the Provincial Exposition, where Picasso won the gold medal. Afterwards, the painting remained in Málaga at his uncle Salvador Ruiz's house where it stayed until he died in 1918 and the painting returned back to Barcelona. Since then to 1970 the big canvas was hanged in the Picasso family house in Barcelona. In May 1970 the artist donated it to the MPB in order to be integrated into its collection. In the same year, the painting was treated in the conservation studio of the Museus de Barcelona at the Museu Nacional d'Art de Catalunya (MNAC) in Barcelona. The fabric was relined and mounted on a new stretcher, the paint losses were retouched and the painting was varnished. Since then it has been displayed in the museum galleries and was only loaned in 1980, to participate in a Picasso exhibition organized at the Museum of Modern Art (MOMA) in New York.

In 2008, scientific analyses were performed on "Science and Charity" for the first time. X-ray radiography was recorded to assess the condition of the original fabric and to study the artist's technique. Moreover, several micro-samples were taken to define the cross-section of the painting materials. The results of this research were presented in the framework of an exhibition entitled "Ciencia y caridad al descubierto" and were published in the exhibition catalogue [9].

This study was the first objective approach to the pictorial technique and allowed to document Picasso's working progress better. Among the results obtained, the X-ray radiography revealed that the artist had worked in multiple sessions on it making several modifications in the composition. In some areas of the painting, as in the blanket, up to seven successive colour applications were observed and, in most cases the subsequent layers of paint had been applied when the previous layer was completely dry.

Artwork	Technique	Place and date	Size (cm)
MPB 110387	Charcoal on paper	Barcelona, 1896	10.5x27.7
MPB 70802R	Charcoal and Conté pencil on paper	Barcelona, 1896-97	28.0x47.5
MP 409(r) Zervós XXI, sheet 46 [10]	Brown ink, watercolor enhancements and violet ink on paper	Barcelona, 1896	16.5x22.2
MPB 110099	Oil on canvas	Barcelona, 1897	23.8x26.0
MPB 110089	Watercolor on paper	Barcelona, 1897	22.5x28.6
MPB 110229	Oil on panel	Barcelona, 1897, dated on the reverse March 1897	19.5x27.2
Zervós, VI, sheet 46 [10]	Watercolor, ink and pencil on paper	Barcelona, 1896-97	37.0x25.5
MPB 110214	Oil on panel	Barcelona, 1897	13.6x22.4
MPB 110046	Oil on canvas	Barcelona, 1897	197.0x249.5
Zervós, I sheet 10 [10]	Oil on canvas	Barcelona, 1897	38.0x48.0

Tab. 1 - Artworks in the MPB collection related to the genesis of "Science and Charity" listed chronologically (in bold the work of arts investigated in the present study).

Another relevant observation was the establishment of reasoned correspondences of "Science and Charity" with other works of small format: six from MPB and other three belonging to other collectors. These small size paintings, which were documented up to 2008 as preparatory sketches, were instead key-documents that were an active part of the creative process of "Science and Charity". They did not only allow a chronological sequence (table 1), but also helped illustrate the different execution stages of "Science and Charity" in a visual way since each of them represents the transition to the subsequently step the painting passed through until the final version was completed, thus forming a first-order documentary set.
The significant modifications in depicting the small size paintings when compared to their final version together with the changes of composition, light and colour show the effort made by the young Picasso in refining and improving the narrative realism and pictorial composition of the painting.

Fig. 2 - painting MPB 110099 with reported the investigated spots.

3. Considerations about the investigated sketches

Within the framework of the ProMeSA project, it was decided to study the four oil paintings belonging to MPB (MPB 110046, 099, 214, and 229, see table 1) to establish their different physicochemical correlations with the aim to better understand the condition of the painting. Examination methods based on the results of spectroscopic studies with spot, visible and near infrared fibre optic reflectance (FORS), and imaging, reflectance hyperspectral imaging (HSI), spectroscopic techniques have been considered. Moreover, in 2010 a set of micro-samples taken from the canvas painting "Science and Charity" (MPB 110046) only was analysed by using scanning electron microscope (SEM) and Fourier transform infrared (FT-IR) techniques. However, this article is mainly focused on the colorimetric data that were acquired by using a Konica-Minolta CM700d spectrocolorimeter [11].
The first colour sketch considered was the MPB 110099 (Fig. 2). It is a quick sketch made with some clumsiness on a piece of cloth that Picasso probably abandoned without going to the canvas as it did not resemble the final version.

Fig. 3 - painting MPB 110229 with reported the investigated spots.

The second preparatory oil painting MPB 110229 (Fig. 3), dated by the artist on the verso of the panel March 1897, presents a more similar structure to the final version. Here, the nun is in centre of the scene next to the main characters, she stands close to the bed with a cup in her right hand and holding the child in her left arm, who is naked and looks younger than in the final version of this representation. The sick woman does not look at the doctor and her right arm lays on the bed with her hand hold by the doctor. The main character of the composition, the doctor, is now sit in profile but he is depicted in a three-quarter view like in the final big canvas painting. However, there is still a big difference between this version and the final one: the doctor, indeed, has here white hair like in the first sketches, including the watercolour (MPB 110089). From this version on the window is on the right part of the scene.

This work maintains the luminosity of the previous version with a great brightness and the palette abounds in white, grey and ochre. The only dark colours, which will persist throughout the execution process, are the black of the doctor's frock coat and the dark blue of the nun dress. Finally, the image extracted at 1300 nm (IR reflectography) shows a curious detail. In this oil sketch, Picasso tries to sit him on a rocking chair, whose skates will later cover with light paint to turn it into a chair. This detail does not lead to the final version either because the final painting identifies the rectilinear structure of the legs of the chair.

In the painting MPB 110214 (Fig. 4) the artist makes a radical change approaching the final version. He has dressed the boy in a red suit and has rectified his position by placing him in a higher position. In this way he is slightly separated from the mother to connect him physically with the nun, who has also turned to a three-quarters position. The figure of the doctor is already acquiring the physiognomy of Picasso’s father, Don José. All the figures of this sketch have a certain disproportion with the format of the board support, indicating that it is a quick sketch to make a chromatic and tonal study while maintaining the basic composition. In this sketch, and by extension at this moment of the final work, the palette changes completely and overshadows the scene. It seems that Picasso gradually darkened the composition: he decided to cover with a rough ochre blanket the white sheet of the bed, applied a dark brown coat on the light grey background in the doctor's area and literally closed the window by turning off the white of the preparation with a very thin brown coat.

Fig. 4 - painting MPB 110214 with reported the investigated spots.

From this moment it seems that the work was already established in its final version except for the frame in the centre of the wall, which on the other hand appeared in the Zervos version. This fact suggests that Zervos is the last sketch done by Picasso before completing the final version of “Science and Charity” [10].

4. Colorimetric data

Even if the four oil paintings do not present identical structures and compositions, such as position and number of the characters, furniture, interior design, etc., early analytical results indicate the use of similar painting materials. For this reason, it was decided to select ten spots on each artwork, corresponding to the most representative hues and details of the final painting. In detail, the selected spots were (Figs.1-4): 1) on the wall in the background in the centre of the scene; 2) the brownish window curtain/shutter; 3) face of the sick woman; 4) face of the doctor; 5) face of the nun; 6) white bed sheet; 7) right sleeve doctor’s jacket; 8) the blanket or the sheet at the end of the bed; 9) nun’s dress; 10) child’s dress.
For the first sketch (MPB 110099) the spot n.10 was not considered as the child was not included in the scene.

	MPB 110099			MPB 110229			MPB 110214			MPB 110046		
	L*	a*	b*	L*	a*	b*	L*	a*	b*	L*	a*	b*
1	40.5	1.0	1.2	39.4	-0.5	11.0	42.6	-0.4	4.3	39.6	-1.6	1.7
2	51.5	3.9	14.1	53.3	4.3	24.2	32.2	4.1	3.7	29.4	5.9	5.8
3	47.6	5.0	14.6	33.3	4.1	11.2	35.6	4.3	9.8	49.8	6.2	18.5
4	51.9	5.4	9.8	30.8	1.3	10.6	29.8	1.1	2.9	39.3	7.6	10.0
5	54.1	4.1	7.6	38.7	12.0	14.6	38.5	4.2	9.5	47.7	6.5	16.0
6	51.1	0.7	9.0	37.4	7.4	18.5	36.2	4.5	7.3	57.1	2.6	11.3
7	41.2	0.1	2.0	26.0	0.6	3.2	25.1	-0.4	-0.5	26.8	-0.3	-1.4
8	48.8	0.0	4.1	45.5	1.4	10.8	42.4	5.0	15.1	40.4	4.5	14.5
9	32.8	0.2	0.3	34.5	-2.9	0.5	27.0	0.0	0.0	25.6	-0.1	-1.2
10				33.2	12.1	12.2	34.6	11.2	10.3	46.5	3.6	9.1

Tab. 2 - L*a*b* (10°/D65) colour values of the investigated areas for the four oil paintings.

Measurements of the chromatic parameters were carried out with the spectrophotometer Konica-Minolta CM-700d model (Fig. 5). This instrument measures reflectance spectra with an acquisition step of 10 nm in the 360-740 nm range. Measurements were acquired using the geometry of diffuse lighting, angle of view of 8° with respect to the normal and exclusion of the specular component, using the 3 mm in diameter probe-head [11]. The colorimetric data reported in this work were calculated in the CIEL*a*b* 1976 colour space for the 10-Supplementary Standard Observer (1964) and daylight D65 illuminant (table 2) [12-15].
From the colorimetric point of view (table 2), it is interesting to follow the trend in colour modification of the different selected areas and to compare these data with the visual description of these changes. Even if *a priori* the materials used by Picasso were not analysed in depth for the four selected paintings, it was supposed that the artist used the same pigments for depicting the four scenes, maybe in different mixtures and concentrations, despite the type of supports, canvas or wood, used.

Under this point of view, the colorimetric data could have been compared as the support did not affect the final colours.
The 'atmosphere' of the scene is given by the hue of the walls of the room. From these data no noticeable discrepancies among the four paintings was found: a medium-light grey inhomogeneous hue on the main wall that is more neutral (achromatic) for the first sketch and the final paintings than the other two intermediate sketches, which instead present a bluish predominance.
The second spot shows a strong variation in hue passing from one sketch to the others and it turns to be a saturated and dark brown colour in the final version. It is noteworthy to stress that the resulted colour is more neutral (a small red and yellow contribution) in the last two paintings than in the first two sketches where the yellow tint is more dominant.
The face complexion of the three adult figures presents differences within each painting and among them. This is in agreement with the fact that the first three paintings are small sketches in which the authors did not have the necessity to refine the faces. Moreover, the colour of the skin was used by Picasso to reveal or support the health status of the different characters.

Fig. 5 – acquisition of colour measurements on the "Science and Charity" painting.

The sheet on the bed is whitish with some chromatic dominant turned into yellow. Only in the third sketch it results more neutral with both yellow and red contributions.
The bluish dark jacket of the doctor shows a more or less constant shade throughout the genesis of this artwork.
The blanket on the bed was inserted starting from the last sketch. However, the colorimetric values do not present huge differences passing from the first two sketches to the last one and the final painting. This fact can be explained with the creamy hue

of the first two works, which, at the end, is not so different from the yellowish brown final hue.
The nun dress is almost black in all the versions but the second one in which it is depicted is a bluish dark tone.
The final spot, the child, shows three different situations: naked child, child with orange-red cloth, child with a reddish-lily shirt. However, the colorimetric parameters for the two cases are almost identical, which is due to the similar tones of the complexion and the cloth of the child. In the last version the child dress presents diverse colorimetric values than the first two, as expected.

5. Some final considerations on the depicted scene

In this research, measured colorimetric values obtained from reflectance spectra of relevant areas are presented and the evolution of the tones and hues used by Picasso to enhance drama through the scenes represented in the four paintings selected is discussed. Despite differences observed in the colour perception of the four painted scenes are evident by naked eye, colour measurements provided clear and objective information about Picasso's early palette to depict the emotion implicit in the scene. From a psychological and artistic point of view, the natural scale dimension of the characters transmits emotion and conveys veracity of the scene in the final version of "Science and Charity". Nevertheless, it is throughout the transformation of the chromatic rendering of the depicted scenes that Picasso managed to accentuate the drama. The contrast between the clear and cold architecture and the areas of shade increase the dramatic atmosphere as does the counterpoint between the healthy characters and the sick woman. Each single detail in the depicted scene oozes pathos and fate. Doctor's rigorous presence in front of the emaciated patient face. The pallor is accentuated plastically by the contrast with the white of the sheet, but also by the wise choice of pigments. The artist always used lead whites (both pure, in the mixtures and in the complexions) but here he decided to add zinc white in making the skin of the face of the sick woman to accentuate her mortuary complexion. These two white pigments were identified by means of FORS and HSI techniques [16].
The healthy looking child, on the other hand, offers a positive view of life. If, in one of the first versions he is undressed and directing his arms towards the mother, in the successive stages the drama decreased: in the sketch MPB 110214 he appears dressed and in the final painting he wears a nice dress and gathers his arms, thus remaining connected to the protection of the nun.
The doctor is presented as a figure of dignity, dressed in a sober black frock coat that contrasts with the shining white collar and sleeves. In this way, Picasso completely transforms the luminous initial idea and places the characters in a *chiaroscuro* framework charged with drama.
Nevertheless, it has to be reminded that this big canvas painting was made by a 15-year old artist and even if some elements do not exactly correspond to the reality (i.e. despite being technically well executed the cornucopia that decorates the wall of the bottom is a discordant element), the quality of the painting itself and the message sent to the observers is still powerful.

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Painted or not painted? Discovering color traces of ancient stones

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1. Introduction

In recent years, a strong interest on the residual polychromy on marble statuary emerged. Although many ancient civilizations used polychromy on stone sculptures and architectural elements, today only a few, almost invisible traces of these colours survive. As a result of these losses, in the minds of a very large majority of people, sculpture and monuments are considered not to have been colored since their creation. Understanding ancient polychromy is indeed a crucial issue since the lack of attention to this theme leads to a significant misunderstanding of both the artwork itself and of the artistic culture it represents.

A correct reading of the original aspect of an artwork is often difficult due to the small amount and condition of the colour remaining. This is linked to the vicissitudes the sculptures underwent over the centuries, such as exposure to harsh environment or burial. In some cases, the polychromy did survive over the centuries, only to be extensively removed after hasty archaeological excavations, in order to reveal the Neoclassical white «pure form» of the sculpture.

The debate on the polychromy of ancient sculpture was already active in the nineteenth and early twentieth century, but only in 1982 it did a breakthrough in the studies with the research project initiated by von Graeve on the polychromy of ancient sculptures [1].

From then on, the issue of color received a growing interest: in archaeology, a rising importance was given to the role of colour in understanding ancient cultures; furthermore, the technological development of non-invasive or micro-invasive tools supported these emerging archaeological ideas with archaeometric studies.

These new studies and collaborations were particularly evident starting from the travelling exhibition Bunte Götter, Munich (2003-2004); I colori del bianco, Rome (2004); ClassiColor, Copenhagen (2004). This exhibition was born by the collaboration among V. Brinkmann, J. Østergaard and P. Liverani [2], pioneering scholars in this field.

This high-profile exhibition of painted Greek and Roman casts, carefully studied and reconstructed by experts from across Europe (Fig. 1), attracted extensive media attention and turned out a renewed interest in sculptural polychromy in both popular and academic circles. This international initiative set the scene for a number of important projects, leading to a very noticeable increase in documentation and publications [3][4][5].

Fig. 1: Modern color reconstruction of Trojan Archer, Temple of Aphaia, Aegina, c. 490 BC. Munich, Staatliche Antikensammlungen und Glyptothek. Credits: Prof. Paolo Liverani [5].

2. Methodological approach

The archaeometric studies allow gathering information about the material composition and state of conservation of polychrome marble artworks. The small amount of these coloured traces lead to a new approach for their characterization. In addition, since traces of polychromy are rare and fragile survivals, non-invasive methods are always preferable. In this way, the residues of polychromy remain intact for future generations.

A non-invasive approach permits the examination of a very large number of artworks with a virtually limitless number of analytical acquisitions allowing to perform measurements *in situ*. Already during the measurement process, this approach leads to a fundamental exchange of views among scientists, archaeologists, conservators and museum experts.

The non-invasive scientific protocol proposed, is characterized by the combination of complementary analytical techniques. The essay is based on a preliminary documentation of the surfaces by means of multispectral imaging. This survey is based on photographic techniques using different radiation [6]; from the ultraviolet (UV) to spatially characterize the presence of organic and inorganic materials, to Visible Induced Luminescence (VIL). VIL is a photographic technique developed at the British Museum in 2009 that can detect the Egyptian blue which is a calcium-copper based pigment ($CaCuSi_4O_{10}$) [7][8]. Egyptian blue is often preserved in extremely small quantities in the porous surfaces of ancient objects, which makes it hard – if not impossible – to identify the pigment even with a microscope. The pigment has, however, the unique property of absorbing visible light and emitting it as infrared radiation. The luminescence emitted by the pigment grains can be recorded with an infrared camera. The technique thus exploits the powerful emission identifying single particles of Egyptian blue, which would be otherwise undetectable [9]. The luminescence phenomenon is illustrated in Figure 2 where the image in visible light and the VIL image of marble mock-ups painted with different blue/green pigments are compared. The white glow represents Egyptian blue (B) and two Chinese pigments (Han Blue and Han Purple) while the others pigments almost disappeared.

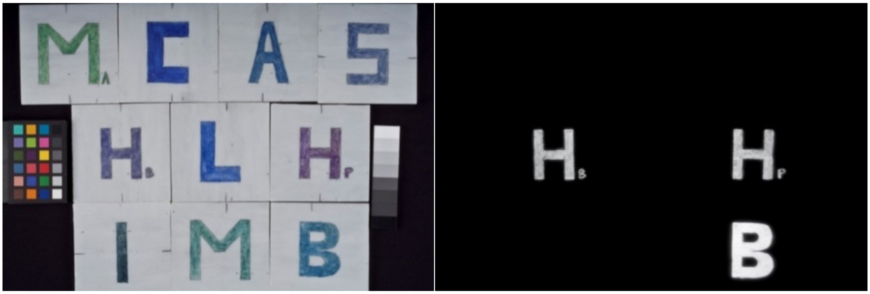

Fig. 2: Visible (left) and VIL (right) images of marble mock-ups painted with different pigments (tempera): M=malachite; C=Cobalt Blue; .A=Azurite; S=Smalt; H_B= Han Blue; L=Lapis lazuli; H_P= Han Purple; I=Indigo; M=Maya Blue; B= Egyptian Blue.

The efficacy of a multi-analytical approach is extremely evident in Fig. 3 in which an area of a decoration on a sarcophagus with tiny trace of polychromy is investigated under different wavelengths and filters combinations [10].

VISIBLE UV VIL

Fig. 3: Example of application of imaging technique on a polychrome marble sarcophagus. a) Visible image; b) UV image where the fluorescence of red lake is visible; c) VIL image where Egyptian blue particles (not visible at naked eye) are instead clearly visible.

Addressed by the imaging results, analyses performed by X-Ray Fluorescence Spectroscopy (XRF) [11], UV-VIS Reflectance Spectroscopy (FORS) [12] and total Reflection Infrared Spectroscopy (TR-FTIR) [13] are performed in order to gain molecular and elemental information on a wide range of inorganic and organic painting materials, including most pigments, colorants and binders [10] [14].

Today, despite important results achieved within the last few years, research on ancient polychromy is still at an early stage and shows some obvious limitations pertaining to the transferability of methodologies or findings. Some interdisciplinary teams already integrate analytical and archaeological competences. One example is the work done at the Ny Carlsberg Glyptotek in Copenhagen, within the framework of the Tracking Colour project [15]. In the published reports, a multidisciplinary approach to study a large group of materials is highlighted [16].
The same approach, a collaboration with archaeometric competencies and the archaeological ones, drove our researches in the last years [10][13][17]. In this paper

some examples of findings in different contexts from museums to archaeological sites will be presented.

3.Examples of color traces studies

3.1. Catacombs

The first case-study here presented is a sarcophagus with strigilated lateral parts and a central scene depicting two figures (a male and a female and several other objects and animals). It is preserved in the Catacomb of St. Pamphilus, on the Via Salaria Vetus, at the deepest level.

In the slab showing the dextrarum iunctio between Olympus Antistianus and his wife Octavia Irene, the surface revealed traces of red and blue colours, especially on the robes and the altar, which were slightly visible to the naked eye. All the red traces showed characteristic ultraviolet fluorescence enabling to hypothesize the use of a red lake for creating the red details (Fig. 4).

Fig. 4: Visible and UV fluorescence image of red lake on Olimpus Antistianus and Irene.

Analyses using the VIL technique revealed the presence of Egyptian blue in some specific part of the bas relief such as the basin or the pillar of the flame (Fig. 5).

Fig. 5: VIL images of some details of the Antistianus sarcophagus

Data acquired with other punctual techniques (XRF, FORS) confirmed the findings and the hypothesis drawn observing UVf and VIL images [18].
In this case, micro-climatic conditions of the catacombs are suitable for the preservation of colours on stone. Temperature and humidity are constant and the lighting is limited to the duration of either visits or inspections. These conditions facilitate the conservation of polychromy, allowing detailed investigations that can highlights important details about the technique used by the old master painters.

3.2. Outdoor and indoor statuary

Etruscan Gens Statlane's sarcophagi, are part of the Florence National Archaeological Museum collection, currently preserved in the courtyard of Villa Corsini, located close to Sesto Fiorentino. These sarcophagi are dated back to the first half of the third century BC.

The group consist of ten sarcophagi. Among all the sarcophagi only VIL survey performed on sarcophagus of Vel Statlane (Fig. 6) highlighted an interesting residue of Egyptian blue on the lower part otherwise not visible at naked eye.

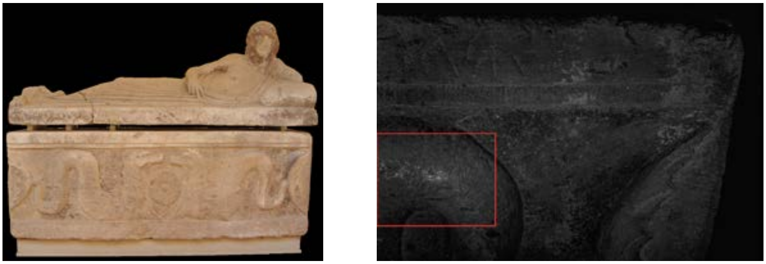

Fig. 6: Sarcophagus of Vel Statlane, son of Sethi, 275-250 BC, Villa Corsini, Florence (left) and VIL image of a detail of the lower slab (right).

Conversely, the sarcophagus belonging to Ramtha Ziltna, is the only one, among those analysed, showing the presence of red lake. The characteristic red/pinkish fluorescence appears on the belt and the ribbon of the woman portrayed on the lid. FORS spectra acquired on this area confirmed this hypothesis.

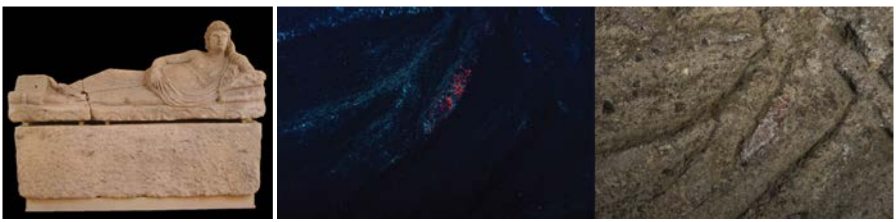

Fig. 7: Tomb II, female sarcophagus of Ramtha Ziltna, 260-50 BC, Villa Corsini, Florence (left) and UV fluorescence and visible images of the detail of the ribbon.

On other sarcophagi belonging to this group also traces of red and yellow ochres were identified (data not shown). The rare traces, almost invisible, discovered during the study did not allow us to establish with certainty the extent of polychromy, but for sure the sarcophagi were painted. This is also confirmed by the documentation of the excavation and by the observations of scholars shortly after the excavation. The sarcophagi were always described as polychrome artifacts.

The poor conservation of polychromy may be correlated to the lithotype used (Nenfro stone, Tuff), that is coarse and prone to disaggregation but also to the stressful conservative history. Indeed, after the excavation, at the beginning of XX century, the sarcophagi were displayed in the courtyard of the museum, exposed to light and rain for more than 50 years, where in 1966 they also suffered the dreadful event of the flooding in Florence.

3.3. Excavated statuary

An interesting example of residual polychromy is represented by the Headless Cuirassed Emperor, belonging to early Imperial cycle from the Augusteum of Rusellae (Roselle, GR) exposed in the Archaeological Museum of Grosseto. Tiny traces of gold have been discovered on the drapery (Fig. 8b) and traces of Egyptian Blue survived on the cuirass (Fig. 8c).

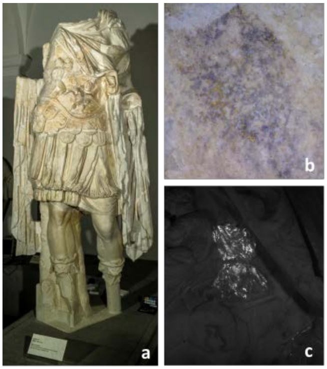

Fig. 8: Headless Cuirassed Emperor at the Archaeological Museum of Grosseto, b) macro image of gold residual, c) VIL detail of the cuirass.

Also in this case few traces of color/decoration were identified but they were enough to confirm the practice of painted and colored statues. Even in this case the poor conservation of polychromy, apart from other reasons, is surely closely related to conservative history. From documents found during the study it emerged that after the excavation (in the 1950s) the statues were cleaned by immersing them in tanks with sodium hypochlorite and "heavily brushed" to remove the excavation earth.

4. Virtual reconstruction of the ancient color

Digital reconstruction of ancient polychromy is a relatively recent issue in the history of archaeological and architectural heritage documentation. It emerged as a result of new interest in the experimental archaeology and the technological development of computer graphic tools.

The standard research activity has been recently supported by the development of experimental approaches, often based on digital technologies to propose and assess reconstruction hypotheses. Those hypothetical reconstructions of the original colors and decorations, previously exemplified on physical replicas of objects, are now moving to the digital media. They are usually reproduced on digital photorealistic three-dimensional models, obtained with scanning technologies [19]. The color reconstructions, based on the results of scientific analysis and archaeological data, allow the visualization of the original appearance of the artwork helping scholars to understand how and why colour was used to decorate or finish the artworks.

Anyway, the reconstruction of the original polychromy is not yet a consolidated subject of research; a lot of work still has to be done to improve our knowledge of the methods and techniques of colour application on polychrome artworks [15].
In addition, the virtual reconstruction becomes more difficult in the context of ancient polychromy, because just tiny and deteriorated samples are usually found.
Today, MeshLab software [20] was used to support the polychrome reconstruction stage and Blender [21] (or, rather, a combination of MeshLab and Blender) was used to achieve a more sophisticated visual presentation of the current and reconstruction ancient color [22].
Previous projects tried to realistically simulate the original colour of the works of art. An interesting example was the one supervised by Prof. Paolo Liverani, which returned a 3D model of the Augusto di Prima Porta at Vatican Museum, complete with its decorative apparatus [23]. In 2002, the Stone Restoration Lab of the Vatican Museums started a careful and painstaking cleaning which has brought back to light many traces of color that were no longer visible. To understand the nature and the composition of the pigments, they were subjected to a scientific examination by analytical techniques. The results of these investigations showed that colors were applied on the clothing, on details of the armor, on the hair and on details of the eyes but not on the skin or on the ground of the armor.

On the basis of these evidences, a complete reconstruction of the colors was prepared on a plaster cast (Fig. 9). The surviving traces are sufficient to permit the colors to be reconstructed over most of the surface. The missing parts were supplemented in a hypothetical manner based on the logic of the use of colors on the statue and on comparisons with roughly contemporary portraits [24].

Fig. 9: The Augustus of Prima Porta and the cast with color virtual reconstruction, Vatican Museums. Credits: Bernard Fischer.

5. Conclusions

The detailed knowledge of an artwork or archaeological artefact, in terms of its composition, is a prerequisite condition for any research in art history or archaeology as well as for any conservation-restoration procedure. The scientific approach here presented represents a strategic tool for achieving a complete awareness of the residual polychromy on ancient statuary; it will open up new understanding of polychrome statuary, supporting more correct and conscious restoration procedures (e.g. in the case of the archaeological excavations or programmatic operations in the museum collections). The aim is to develop a broader awareness of residual polychromy to be shared with the research groups active in this field on the national and international scene, with the museums and institutions involved in conservation of cultural heritage and for educational purposes with non-specialist public.

The technical examination is based on the use of several non-invasive methods. In this way, a very large number of artworks with a virtually limitless number of analytical acquisitions can be analysed. This approach leads also both to the reduction of the sampling activity and to a fundamental exchange of views among scientists, archaeologist, conservators and museum experts, already during the measurement process.

One still open issue is represented by the assessment of the reliability of the digital color reconstructions. Until now it has not been possible to create realistic renderings that take into account the effect of color with the material (marble or other supports) and light.

Further improvement could be dedicated to testing the actual system to assess the effectiveness and limitations to recreate a hypothesis of the original colour (on the digital reconstruction).

Very often the extent of the surviving pigments/color is too small to allow a satisfactory reconstruction of original appearance. The latter is a combination of several parameters, such as pigments but also binders, thickness, preparation layers, etc.) that are not always known. So the reconstruction is something very risky that can easily turn into a modern reinterpretation.

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6. COLOUR AND BUILT ENVIRONMENT

Color Allegories: Progressions, Pretensions, and Pride in Art Deco Murals of New York City

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1. Introduction

This paper offers an in-depth study of color allegories illustrated by palettes of original Art Deco murals in New York City's Rockefeller Center complex. In this text, the definition of "mural" is expansive, including as a broad category of interior and exterior designs integrated with a facade or wall surface. This definition includes works in media such as paint, limestone, enamel, oil, sand, leather, Pyrex, glass, steel, metal, mosaic, and more. The methodology of analysis includes (1) color documentation at the building sites using the Pantone Matching System, (2) documentation of materials in the murals, (3) compilation of color and material palettes, (4) photographic essay of murals, and (5) text analysis of the significance of color and material palettes in relation to themes of the Art Deco era. Select color palettes and materials are shown within the text. Analysis of other murals on site can be provided upon request. All images by the author unless otherwise noted.

2. Early Color Design Planning at Rockefeller Center

Rockefeller Center debuted in 1933 as a celebration of modernity, commerce, and philanthropy rooted in forward-thinking ideas. In a convoluted and much criticized journey, John D. Rockefeller Jr. – famed New York financier and member of the elite Rockefeller family – launched this iconic and highly successful complex of Beaux-Arts axial planning, this "a city within a city" [1]. Rockefeller obtained an enviable team of experts to implement his vision. Leading the group were established skyscraper architect Raymond Hood and industrial designer Donald Deskey.

Dark horse candidate Deskey was chosen as interior designer out of a shortlist of elite and established design firms. His inclusion in the design process was instrumental and integral to color presence at Rockefeller Center. His atypical pitch for the commission featured panel after panel of opulent colors, textural materials, and finely-crafted artwork samples, the latter created with local experts from the American Union of Decorative Artists. With his impressive spread of colors and textures, his acknowledgment of the "strange beauty in new industrial machines and material," and his modernist clean Bauhaus design sensibility, he earned a spot on the coveted designer roster at Rockefeller [2].

The initial design process of the Center included an overall color coordinator, the noted painter Edward Trumbull (of the Chrysler Building lobby ceiling mural). He oversaw hue choices around the entire Rockefeller Center complex – from color palettes of individual artworks to material finishes in interiors. In order to obtain the commissions, artists of works on site were required to create in tandem with the site's color consultant, Léon-Victor Solon. Solon, as Art Director of American Encaustic Tiling (whose father was an internationally established porcelain designer), was conveniently intertwined in the network of big designers of the day and in prime position to be selected for the esteemed color consultant task [3]. Rockefeller incorporated a grandiose art program into the Center's plans, and his financial allocations proved his serious dedication to art in the complex. He allotted a heady $150,000 for artworks and assembled an Advisory Art Committee for the Center [4]. With Hood, Deskey, Trumbull, and Solon supported by an invested patron offering a heavily funded art program, color was a serious, strategic, powerful, and omnipresent force in this history-changing complex.


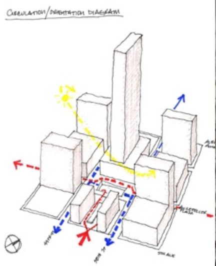


Fig. 1 (left) –The view from Fifth Avenue culminates in the lofty tower of 30 Rockefeller Plaza.
Fig. 2 (middle) – An aerial sketch of Rockefeller Center illustrates the Beaux-Arts grounded axial plan of the site [17].
Fig. 3 (right) – Entering the complex from Fifth Avenue, a pedestrian encounters the Channel Gardens and Promenade en route to the central plaza.

3. COLOR AS PROGRESSION: Central Axis of Channel Gardens and the Promenade between Fifth Avenue and 30 Rockefeller Plaza Entrance

Seeds of Good Citizenship (1937) on La Maison Française and *Winged Mercury* (1933) on the British Empire Building, Lee Lawrie with colorist Leon V. Solon; intaglio relief of polychrome and gilding on limestone [5]

A societal shift from omnipresent anemic, achromatic architecture of the prevailing decades to more colorful built structures began to surface in the first two decades of the 20th century. In 1909, hints of the "color revolution" to come spread with the notoriety of the light-drenched terra cotta of New York City's Woolworth Building and with colorists becoming regular members of payrolls at Detroit's finest car companies [3]. In 1924, Rockefeller Center's architect, Hood, blasted New York City with massive, shocking black and gold sheathed structure – the hulking American Radiator Building, a color-heavy abstract palace-cum-radiator. In the same year, established Gothic Revivalist architect Ralph Adams Cram (whose buildings were not particularly chromatic) observed, "The manner in which color is coming, for instance, into the commercial architecture of Fifth Avenue it is itself indicative to the change that follows the demand" [6]. Furthering the color movement, the authoritative Exposition Internationale des Arts Décoratifs et Industriels Modernes of 1925 in Paris paraded buildings with gilded accents and showcased colored murals integral to architectural design [7]. As seen in top

magazines of the time, color had carved a place for itself in high design as well as in public culture.
In essence, Solon's time to reach color glory had arrived. He was against the architectural community's "antiseptic, xenophobic approach… Surveying American culture through European eyes, he detected a unique spirit in the strange, dynamic rhythms of jazz music and ventured that color would be the next vehicle for American self-expression." Solon, also known as "Prince Polychromy," had experience to back up his grandiose theories as he had he just completed the watershed color design of the façade of the Philadelphia Museum of Art. His methodology included the hoisting of full-scale sculptures of "scarlet, vermillion gold, black, buff, blue, and green" onto the "golden-orange stone," a practice that emulated the ancient Greek building tradition of envisioning color as a fundamental part of the building design. The Museum was called a "monument to color planning that balanced ornament and mass, adapting the glories of ancient polychromy to urban industrial America." Here, color proved a powerful driver in the conceptual and formal development of architectural design. [3]

Fig. 4 (left) – *Seeds of Good Citizenship* illustrates Greek methods of color arrangement on La Maison Française along the Channel Gardens and the Promenade.
Fig. 5 (middle) – Solon's *Polychromy* book of 1924 depicts color reconstruction of the Portico of the Propylaea.
Fig. 6 (right) – *Winged Mercury*, crafted with color in relation to form, glides along the façade of the British Empire Building next to the Channel Gardens and the Promenade.

Like the Greeks, Solon insisted on color being integral with form: "Tonal quality is produced by ingenious combinations of concave, convex, and angular… to develop extremely delicate gradations in color-tone" [6] [3]. He applied this theory in the striking, but not overpowering, use of color at Rockefeller Center. The Channel Gardens, an elegantly downward sloping pedestrian pathway driving down the axis from Fifth Avenue to the grand entrance of 30 Rockefeller Plaza, parades Solon's color choices gracing the three-dimensional forms of sculptor Lee Lawrie. The color designs peripherally mark moments as a pedestrian strolls into the center of the complex. Solon's color implementations subtly highlight the site's dominant Beaux-Arts axes and lead physically and visually downward to the colorful destination point at 30 Rockefeller Plaza.
Just as the colors of *Winged Mercury* direct progression in physical space, so, too, they convey trend-forward thinking of the era's ideological movements. Colors at this time spawned from the work of the Fauve painters – whose hues often did not

Fig. 7 – Rockefeller Center's *Winged Mercury* (left) and the costume for the *Ballets Russes* (on right) share color palettes as metallic gold, black, and green-blue combine in diamonds and arcs of vibrant dimension.

match the real color of the objects depicted, the discovery of King Tut's tomb (with the resultant Mayan-Egyptian-Aztec color craze), and other avant-garde creations. The colors of *Winged Mercury* mimic the palettes of the era's heralded *Ballet Russes*, a production embodying modernist growth in arts and culture.

Exterior Loggia at 1250 Avenue of the Americas

Intelligence Awakening Mankind (1933), Barry Faulkner; over one million hand-cut and hand-set glass tesserae in 250 colors [5]

Fig. 8 (left) – Capped by a gold ceiling, *Intelligence Awakening Mankind* spills thematic color around the loggia.
Fig. 9 (right) – The South panel of *Intelligence Awakening Mankind* depicts evil being defeated in a swirling, tumbling mass of vibrant oranges and greens.

Fig. 10 (left) – The central figure depicts Thought draped in red floating on white and blue streamlined clouds.
Fig. 11 (right) – Heightened by the deep blue background of the entire mosaic, the analogous color combination of sunflower yellow and muted red join forces to further the message of working with others towards a common goal.


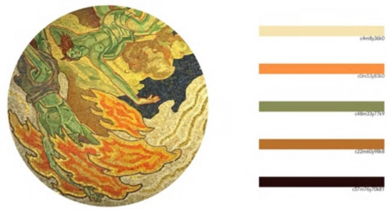

Fig. 12 (left) – The green figure, representing evil, slips to the bottom striped edges of the long wraparound mosaic.
Fig. 13 (right) – More green-hued figures, accompanied by hot orange and bright yellow fire, twist and fall into the descents of hell.

So, too, color sells themes of progress in the mosaics in the loggia of the 1250 Avenue of America building. The imagery illustrates themes of societal progress to depict the "triumph of knowledge over the evil of ignorance". The main figure, Thought, dominates the center of the composition in saturated red fabric, floating on white clouds made more stark and apparent by the surrounding deep blue sky. The mosaicist was asked to create undulating forms as "radiating waves of knowledge," seen here in forward moving streaks of orange being emitted from the likes of angels of Physics, Biology, and Sports. As contrast, green sickly-skinned people, depicted in marked balls of defeat, violently descent into the fiery hell of ignorance. Beyond the direct figurative storytelling, color drives the point home, serving as a vehicle for narrative [5].

4. COLOR AS PRETENSION: Lobby of 30 Rockefeller Plaza

Rockefeller fronted weighty charges backed by ambitious philosophies for personal and public good and worked the art program to feed the same demand:

> "…a monument to the achievements of humanity: a cultural, economic, financial and foreign trade center, which would restore confidence in capitalism, show the world the Rockefeller family's spiritual values and commitment to social service, and promote international relations. It was also to be an ode to the mass media…" [8].

The art theme of the Center was Art Deco-optimistic, slightly showy, and broadly encompassing: "the progress of man" [4]. Rockefeller went further in advocacy of the overall theme, applying more specific goals for artwork scattered around the complex. He charged the artists of the murals inside 30 Rockefeller Plaza to make people pause and think and turn their minds inward and upward… stimulate not only a material but above all a spiritual awakening… The development of civilization is no longer lateral – it is inward and upward. It is the cultivation of Man’s soul and mind… [9]

Rockefeller wanted artists and designers to sell the idea of his complex as a continuation of the growth and legacy of civilization, including murals with direct titles such as *The History of Civilization* and *Aspects of Mankind*.

Not only did this message further the perceived importance of the Rockefeller family achievements, but it also was meant to be a mantra for the people, falling in line with societal themes. At the time, the Deutscher Werkbund manifesto trended ethical treatment for craftspeople in the arts and also equality of art exposure: high art should be accessible to the general public and not just be “objets d’art for the wealthy” [2]. The appointment of Deskey as interior designer, a man incorporating the work of the local guild of craftspeople in his pitch, followed this reasoning.

American Progress (1937) and *Time* (1941) José Maria Sert; oil paint on canvas [5]


Fig. 14 (left) – In smoggy, dirty-colored *American Progress*, Abraham Lincoln and Ralph Waldo Emerson anchor the center ground while the pile of people and tree trunks around them leans to the upper corner of the wall to highlight the architectural volume of the room.

Fig. 15 (right) – Upon entering the lobby and gazing at the ceiling, the visitor is faced with a strong perspectival view of *Time*, featuring an achromatic muscular male figure “standing” on the physical columns holding up the ceiling.


Fig. 16 (left) – The palette of *American Progress* is of warm neutrals as Rockefeller wanted an achromatic palette used in the lobby.

Fig. 17 (right) – In this section of *Time*, the palette is slightly darker than American Progress, creating a sense of weight, heaviness, and shadow on the ceiling.

A sense of moral justice and patriotic fervor prevailed, most clearly evidenced in the highly publicized firing of muralist Diego Rivera initially chosen to paint the central mural in 30 Rockefeller Plaza lobby. Rockefeller, relentless with demands to keep the lobby achromatic, had finally conceded to the pressures of Hood, who was being fiercely pushed by Rivera himself. Rivera attested,

> Hood wanted me to work in a funereal black, white and gray rather than in color, and on canvas rather than in fresco… The theme offered me was an exciting one: "Man at the Crossroads Looking with Hope and High Vision to the Choosing of a New and Better Future” [9].

Rivera fought these color rules, claiming achromatic hues create the “‘feeling of a crypt. Suppose some ill-disposed person should chance upon such a nickname as ‘Undertaker’s Palace’” [10]. Later, Hood’s color concession to Rivera was used as a easy out to back the more controversial decision of taking Rivera’s mural flaunting Lenin off of the entry wall. On May 10, 1933, the New York Times published the header: “ROCKEFELLERS BAN LENIN IN RCA MURAL AND DISMISS RIVERA Check Handed to Mexican Artist and He Is Barred From 'Greatest' Work COLORS ALSO NOT LIKED” [11]. Lenin was eventually replaced with American greats Abraham Lincoln and Ralph Waldo Emerson by Jose Luis Sert in that location, in a mural titled none other than American Progress.

Years later, mural experts later had a color “eureka moment” when real colors were revealed during the restoration at 30 Rockefeller Plaza. They realized that the murals were designed to be in “harmony with the warm, stone color of the marble” but, as the mural varnish had darkened with time, the “color scheme for the whole interior was out of whack.” The restoration experts claimed that, with removal of the darkened varnish, “it was as though we’d switched on the lights” [12].

Although Rockefeller’s insistence on the neutral color palette created controversy, the result of the lack of use of vibrant hues helped foster the Center’s theme. The warm-toned lobby – wrapped in tunnels of clouds, soaring planes, and heroic factory workers proudly toiling to advance our civilization – became a smoky smog machine celebrating the hard-earned progress of American industry.

5: COLOR AS PRIDE: Exterior Murals at Entrance of 30 Rockefeller Plaza

Wisdom (1933), *Light* (1933), *Sound* (1933); Lee Lawrie with colorist Leon V. Solon; carved Indiana limestone, cast glass, paint, gilding [5]

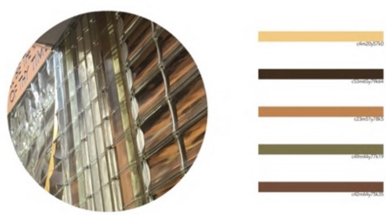

Fig. 18 (left) – *Wisdom* shoots gilding from above to frame those entering 30 Rockefeller Plaza.
Fig. 19 (right) –The glass block lower portion of *Wisdom* reflects and refracts ambient light and color as it anchors the axial path from Fifth Avenue to its location at 30 Rockefeller Plaza.

Fig. 20 (left) – The contrasting hues and values of color in *Sound* amplify messages heralding new technology on the Radio Corporation of America Building.
Fig. 21 (right) – *Light* slides gently along the façade of 30 Rockefeller in a soft, hazed, and feminine celebration of the incredible reach of new technology.

The complex embodies a strong belief in technology—which conveniently supported industries of tenants at the Center (such as, at the time, the Radio Corporation of America). Seeming almost relentless, Rockefeller insisted on the complex as a "celebration of commerce" [4]. The art above the entrance of the tower at 30 Rockefeller Plaza – titled *Wisdom*, *Sound*, and *Light* – beautifully territorialized the most prominent space in the complex, where the axes of the urban plan meet the base of the soaring skyscraper overhead. Mural color contrasts emphasize and celebrate latest technologies – with imagery rendered of combinations in soft warm hues – powerfully reaching out, through, and amongst the [now] throngs of people, seeming to touch the core of our human race. (Solon's belief in the Greek method of outlining color forms with contrasting color segments to have the art readable and powerful, even from far away, serves the purpose of theme proclamation from near and far as well.) Colors at 30 Rockefeller Plaza shrewdly demonstrate Solon's idea of color as "radiating vibrance" and speak to the magnificence of new technologies and the advancement of civilization [6].
The Center flaunted latest material technologies for storytelling effect as well – from the potent huge stainless steel casting titled *News*, lauding the latest technology of information transmission, to the revolutionarily manipulated Pyrex as sculptural material in *Youth Leading Industry*. The site boasted further material and technology experiments on site, boasting the likes of Hildreth Meière-designed medallions on façades facing Radio City Hall that featured enamel at a never-before-used scale [5]. In fact, innovative material applications made it possible for contemporary visitors to experience the color message as Solon's self-formulated paint has "withstood New York City's harsh climate to this day" [3]. As applied to naturally hued materials, Solon's latest technologically tough polychrome color joined forces with the Center's imagery and overall narrative, extolling pride in human achievement. Pride exuded as material shines at other locations on campus, too, as hints of modernist use of color as material phenomenon coat the premises.

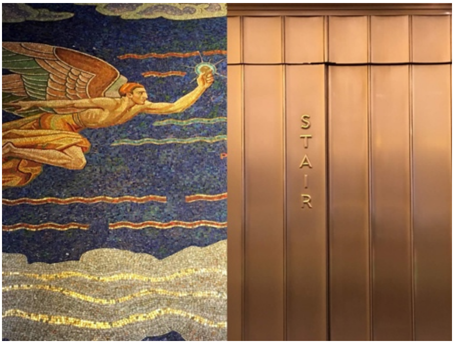

Fig. 22 (left) – Tesserae with applied color while copper cladding on site shines with inherent metallic properties.
Fig. 23 (right) – Sculptor Isamu Noguchi's hefty cast stainless steel, *News*, conveys the gravitas with which new technologies can deliver timely and accurate information.

Copper cladding, marble wall coverings, metal castings… A significant portion of the complex's interior color palette was driven by the material color itself, forwarding the modernist way of thinking seen later in iconic works such as the rich material-clad Seagram Building by Mies van der Rohe in 1958.

6. Conclusion

Rockefeller Center fulfilled most, if not all, claims, hopes, and goals of its founders and designers. Lauded modernist architect Le Corbusier granted his utmost approval, calling the Center a "machine-age temple" while de rigeur culture maker and writer Gertrude Stein claimed, "'The view of Rockefeller Center from Fifth Avenue is the most beautiful thing I have ever seen" [13] [14]. Impressively, numbers of critics – many of whom had been undeniably harsh at the outset of the project – offered praise, touting that the Center showed "remarkable balance between monumentality and friendliness" and was, "though undeniably tremendous, a very welcoming, populist sort of development" [15] [4]. Douglas Haskell, editor of Architectural Forum magazine – once quoted as saying Rockefeller Center was 'gray, unreal, baleful' – found that the designers 'seemed to have regarded urban life as an enhanceable romance'" [16].

Fig. 24 (left) – Spatial sequence of light and color in at 30 Rockefeller Plaza offer opportunities for further study.
Fig. 25 (right) – Red and blue neon offer provocative threads of investigation of color as commercial signage on site.

Fig. 26 (left) – *Wisdom*, as viewed at night, emits soft pinks and violets to passersby.
Fig. 27 (right) – Shadows resulting from carved wall surfaces create stacks of dramatic dark hues.

Fig. 28 (left) – Stone cladding down the Promenade combines warm and color colors to create a soft and textural chromatic path.
Fig. 29 (right) – In a brilliant merging of color, material, space, and message, the shiny metal of the stair railing moves the eye around, up, and into Ezra Winter's mural, *The Fountain of Youth*.

Solon, with his pretentious idealism, was also proven correct as he had ventured to say, "Perhaps, a hundred years from now, one of the things for which 'people will gratefully remember Rockefeller Center… will be its re-pioneering the use of color'" [3]. In fact, historians today call Rockefeller Center a "monument to the color revolution" [3]. In an age of vast change and optimistic growth, color proved a worthy messenger of society's gloriously modernist future.

Future research opportunities are immense but could include such investigations as documentation of the Center's colors as seen with illumination at varied times of day, analysis of other art and/or material detailing on site, examination of color as commercial signage into architectural complexes, and exploration of sequences of colors in relation to spatial flow and overall urban plan.

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Toward a Chromatic Hermeneutics. Color Practices in Architectural Reconstructions between Digital and Virtual Heritage

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1. Introduction: from light to black-and-white[1]

According to scientific address, the term “light” identifies a small range of electromagnetic radiation between 700 and 900 nm. Above and below these limits, at least for human beings, is the darkness. Solar radiations invest all living bodies, but only some photosensitive cells are able to catch and transmit them through the electrical impulses produced by peculiar molecules’ change of state (CIS- and TRANS-) and shape. The diversity of photoreceptors’ selective perception produces a “luminous image” of the space framed by the visual field in the posterior part of the human brain (visual cortex). Thus, the human environment has not only a sensible exteriority but it also looks colorful, especially in the daytime hours; and colors are essential to people in establishing affinities and differences of items moving within their field of view.

In 19th century, the early mechanical reproduction technology, which was still unable to fully developing color pictures, did not allow photography to reproduce the world the way it is perceived. This apparent limitation, however, developed a peculiar sense of chiaroscuro by eventually excluding a bi-univocal relationship between the picture and reality. Since 1834, when William Henry Fox Talbot conceived the “photogenic drawing”, the black-and-white photography has been gaining its own peculiar sense: initially as an objective depiction of reality, by selecting only the bright aspects of reality; and then as an aesthetic product of the individual behind the camera. Thanks to the lacking of colors – or better their translation into grey grades palette – black-and-white photography developed its own aesthetic discourse and contribute to knowledge. As highlighted in 1939 by Paul Valery in his *Discours du Centenaire de la Photographie*, “the eye grew accustomed to anticipate what it should see, and to see it; and it learned not to see nonexistent things which, hitherto, it had seen so clearly”.[2]

Only recently color has become part of the process of mechanical reproduction of perceived reality, and with some difficulties. Before it, the presence of a manual artwork able to “invite” the brain to replicate the perceptive process with which it routinely probes and appreciates the natural environment was as necessary as the presence of someone who could play an instrument to listen to music.

The birth and development of technology for a mechanical reproduction of color almost filled the distance between a photographic image and the visible reality, certainly contributing to an objective documentation of places and facts. Paradoxically, this higher objectivity and accuracy has driven photography away from its natural mission of “representing” reality, showing things for what they are.

2. Coloring the architecture model

Leon Battista Alberti had already indicated the role and risks of the use of color in architectural design models. The Italian literate believed that “the presentation of models that have been colored and lewdly dressed with the allurement of painting is the mark of no architect intent on conveying the facts; rather it is that of a conceited one, striving to attract and seduce the eye of the beholder, and to divert his attention from a proper examination of the parts to be considered, toward admiration of himself”.[3]

Alberti considered painting, in its chromatic and decorative address, as a useful tool for orienting perception and correcting imperfections, too. If the architect’s goal was to exhibit spatial invention, he advised to present models looking like “plain and simple, so that they demonstrate the ingenuity of him who conceived the idea, and not the skill of the one who fabricated the model”.[4] Alberti was also aware of the cultural function of color (and non-color) in architecture. In his choosing the Istria white stone for the Malatesta Temple, Massimo Bulgarelli[5] has identified an instrument not only to link the building to the Roman monuments of Rimini but also to recall a memory of white as the sacred color of antiquity. [6] Alberti himself evoked this function by recalling that Cicero induced his fellow citizens to set aside the frivolity and attractiveness of the ornaments in the construction of the temple, to have it “built of stone not worked by hand, but as found, white and shining”. [7]

In a provocative acceptation, Alberti’s position could be assumed as a sort of conceptual prefiguration of the aesthetical opportunities of the black-and-white photography. While the absence of colors seems to provide the architect with the opportunity to stage the spatial idea before its material incarnation, the use of color and material texture moves the perception from a mental level to a purely sensorial one and activates a semantic connotation that has its roots in the beholder’s cultural substratum. Added to this, factors such as the model’s scale of representation and the detail level can induce either a detached perception, which makes the observer aware of the simulation, or an immersive-like experience, which amplifies the effectiveness of spatial fiction by involving both the sight and the body. [8]

2.1. Digital models

In the last decades, the production of digital models has increased both in the academic and professional fields. Also the production of architectural models in the Digital Cultural Heritage, as a result of either investigations on unbuilt projects from the past or reconstruction of lost, destroyed or heavily altered buildings, has moved from the crafting in wood, paper or plastic to the digital modeling: generally solid models but also with numerical or mathematical modeling integrations. This is due to the widespread diffusion of digital technologies, as well as to the innovative opportunities offered by digital models, in terms of knowledge, dissemination and users’ interaction. The issue of color, which is therefore to be methodologically reframed into this innovative and layered process, is being currently dealt with a diffused ease and unawareness.

Firstly, modeling software designers have been engaging color as an operative key to organize and help the visual recognition of components as well to identify layers and relationships between entities and blocks.[9] In this context, the subtle cultural ambiguity induced by the attitude of identifying certain materials with their habitual color – a light-blue layer for the transparent parts; a green layer for the vegetal elements; etc. – must coexist with the operational implications linked instead to the attribution of specific information relating, for example, to the print output or other model parameters.

Secondly, the availability of an almost unlimited palette of colors is a continuous lure, often favored by the pre-assigned settings, to color the parts according to instinctive and uncontrolled way, with repercussions in all the process' stages. This also leads to a third aspect, namely the possibility of presenting the model through views and animations which, thanks to the rendering engine and a clever work of virtual lighting and material mapping, are able to simulate the textural and photo-realistic effects that can be perceived in nature.

2.2 Rendering after the digital model

The widening of the creative horizons caused by Information Technology (IT) and digital photography have blurred the borders between virtual and real world, the very value of perceived reality being daily questioned. The evolution of Computer Graphics technology has encouraged the development of specific professional figures able to masterfully simulate reality. These Computer Graphic Artists can produce sophisticated and seducing architectural pictures whose main goal is no more – or not only – to illustrate a project but to instill pleasure, amazement, and aesthetical engagement. Generally, a participation in a design contest requires the commissioning of high-quality renderings to a studio specialized in architectural visualization. The work of MIR Office in Bergen, South-Western Norway, is emblematic of this type of visual products. Self-defining itself as "a creative studio specialized in portraying unbuilt architecture",[10] MIR's goal is not simply a photo-realistic rendering but a digital pictorial artwork in which the beholder is dragged and wrapped with a dreamlike effect. In this way, while emotion is distracting from the observation of architecture, the pictorial beauty of the rendering eventually encourages a positive judgement on architecture.

While in the context of an architectural design, the presentation of realistic and highly detailed views belongs to the logic of communication and negotiation between architect's imagination and client's expectations, in the context of a reconstruction the same renderings might peremptorily convey a historical truth that rarely can be properly testified. It is quite common to come across models showing detailed materials and colors, which however neither reveal what is certain nor scientifically specify the conjectural levels adopted. Just to avoid a certain mischievous superficiality that characterized several digital reconstructions realized around 1990s, initiatives and shared documents such as the London Charter[11] are invoking the need for a scientific, open and transparent use of data, the implemented processes and the final results.

As a reaction to this, the practice of mapping the model with a neutral material is quite encouraged in the Digital Cultural Heritage or directly Digital Heritage (DH). Thus, digital models often look like a traditional wooden *maquette* or a generic white-painted one, without considering that no representation can be neutral and even a white architectural model can be unconsciously misinterpreted in a specific cultural frame: like the Greek temple, Francesco Borromini's interiors or Bauhaus-style *Weissen-Hof*. As a specific branch of Digital Heritage, the Virtual Heritage (VH) is generally defined as a kind of user-oriented three-dimensional digital reconstruction. In this context, architectural models should not only have the ambition to reconstruct designs or environments of the past, whose information about colors and materials are sporadic or lacking, in a scientific way, but also to present and disclose them in a "transparent" way, underlining the relationship between documents available, working hypothesis, process of elaboration and results achieved.[12]

3. Modeling and coloring for DH: three experiences

In this section, the authors describe their own choices concerning with color in DH modeling in three different case studies: the three-dimensional reconstruction of Gian Lorenzo Bernini's unbuilt design for a monument to the Spanish sovereign Phillip IV in the Basilica di S. Maria Maggiore in Rome; the three-dimensional reconstruction of some of Leonardo da Vinci's designs for centric buildings on his manuscripts; the modeling of some rock-cut complexes surveyed in Cappadocia between 2007 and 2014 through digital photogrammetry.

3.1. Case Study: Bernini's monument for Felipe IV of Spain

The first case is concerning with a project the Baroque architect Gian Lorenzo Bernini made around 1663 for a monument to Phillip IV of Spain to be built near the Porta Santa, in the left side of the portico of the Basilica of S. Maria Maggiore. [13] The bronze statue of the sovereign is the only constructed part of the project. It was cast by Girolamo Lucenti and is today standing on a tall pedestal in the same portico, although on the opposite end. On the contrary, the sacellum designed to house the statue is unbuilt. The only two known drawings – a design in the Vatican Library and a presentation drawing in Florence Uffizi collection – show a sort of sacred apse temple with a niche and a curvilinear pediment supported by double columns shaping a Serliana motif. Bernini designed the sacellum according to the so-called "solid" or "accelerated" perspective. This would have caused it to look deeper than it would be in reality and, consequently, to increase the apparent size of the statue itself. Added to this, the "alla Bernina" light coming from the hidden windows to the left of the statue would have staged a theatrical celebration of the sovereign's power.

The three-dimensional reconstruction of the project, carried out as part of the studies and documentation for an exhibition held at the Prado Museum in Madrid from November 2014 to February 2015,[14] was mainly aiming at three outcomes:

a. understanding the structure and reconstructing the visual effect of the project;

b. providing educational contributes, such as schemes able to explain the functioning of the solid perspective device;

c. producing a video with an animation useful to contextualize and disseminate this almost unknown design of Gian Lorenzo Bernini in Rome.

The primary witnesses of the digital reconstruction – the two drawings, the statue of Phillip IV and, partially, the portico itself – afforded a sufficient documentation – excluding few integrations linked to some graphical and dimensional inconsistencies

– to proceed with the reconstruction of the sacellum. However, apart from the bronze statue, they provided neither a clue on the materials nor the chromatic role of the parts. After questioning whether to hypothesize a chromatic accomplishment for the sacellum and, in case, how and where to collect data to this purpose, the authors responded positively at the first question, considering that the final product had to be an animation addressed to a wide audience who had to be involved primarily in a sensorial key. Consequently, the necessary secondary witnesses have been found Bernini's architectures showing analogies in size and function, such as several chapels as well the church of S. Andrea al Quirinale.
The raw geometric model of the sacellum, integrated by the numerical model of the statue through photo-modeling, has been applied with materials maps photographically sampled after a selection of polychrome marbles. This model, appropriately lighted, has been then used to shot a brief animation to be inserted into a longer explanatory video. In the Madrid exhibition, this had to contextualize and expand the information framework of the original document – namely the Vatican design – displayed next to the monitor. To make clear the hypothetical character of the material and chromatic reconstruction in the model, firstly a monochrome version of the model is shown in the animation (fig.1a) with the bronze statue emphasizing the only assured material and architectural parts mapped with the white Roman travertine marble. Only later, the polychrome model is revealed and navigated in the video (fig.1b).

3.2. Case Study: Leonardo da Vinci's centric temple designs

Since 2008, the authors have been elaborating and perfecting an innovative methodology of analysis of Leonardo da Vinci's manuscripts, in particular the sheets containing his design concepts on religious architecture. This methodology is based on an integrated analogical and digital process designed to elaborating a diplomatic and interpretative edition of Leonardo's sheets, on the wake of philologists' practice.[15]
The "diplomatic edition" constitutes the first level of decoding and understanding of both the document and the projects on it. In the case of Leonardo's sheets, a preliminary distinction between text and drawings is necessary. In the first place, it allows to reveal and classify the visible graphic consistencies through three steps: rewriting of texts with a special character similar to the Leonardian one, namely inspired by Ludovico Vicentino's Cancellaresca font;[16] mirroring of the texts, famously written from left to right; improving the readability of texts by adjusting the spacing between letters and words. Secondly, the drawings – sometimes only doodles that are difficult to decipher, sometimes layered designs rich in variations and repentances – are reproduced using a graphic tablet. This choice allows to interpret Leonardo's marks by hand, to regularize uncertain lines and to decrease additions as much as possible. Almost imperceptibly, this process encourages the identification between the author and the artist and, consequently, a mental "immersion" in his generating thought.
The "interpretative edition" is the second level of decoding and understanding of the document. It is based on the presence of a single "witness", in this case Leonardo's autograph document. Applying this concept to architectural designs consist of

interpreting them three-dimensionally to get back to design concept. The construction of a three-dimensional model starting from the available schemes allows the authors to retrace the design process, evaluating the overall consistency of the project, and obtaining views to be compared with the original sketches.
The construction of such a model implies the formation of a chain of conjectures. This process is getting started with re-drawing – re-designing, in some cases – the plan in a geometrically structured and regularized shape to achieve the internal and external volume evoked by the sketch. However, while the text is edited directly from the original document, the architecture edition needs continuous verifications of formal feasibility that can be provided only by secondary or indirect witnesses, such as other drawings of the same author, thus turning the interpretative edition into an eventual “critical edition”.
Here, the question of the color of the digital model assumes a peculiar sense. Generally Leonardo’s architectural designs afford neither indication or suggestions to attribute colors or materials. This is also the case of the project here presented, developed after the sketches in the sheet 3r of Codex Ashburnham 2037 (fig.1c). Suggestions in this sense could come from architectures and coeval projects by Leonardo’s colleagues but, in the context of a critical reconstruction, the comparison with the original documents is a priority. The methodological framework suggested the idea of elaborating a specific color palette directly after Leonardo’s ink effects on the old sheets. On the basis of the original tones, digitalized after a photographic survey of the paper document, the colors have been developed in several dominants, in order to mark the architectural role of the parts and to make it easier to memorize and compare the various design hypotheses.

3.3. Case Study: Cappadocian rock-cut architecture

In the experience of surveying and representing some rock-cut settlements in Cappadocia, particularly in the Goreme area, the contribute of color in digital models has been addressed in two different senses. In the first place, it has been taken into account in the process of surveying through laser-scanner, photo-modeling and digital camera the survived graffiti and wall paintings. Added to their remarkable historical and artistic value, sometimes they are properly part of the rooms’ architectural concept, contributing to the general fiction of being inside a traditional church with capitols, vaults and furniture. In these cases, their reproduction has been a fundamental part in the architectural representations of the rock-cut settlements. The methodological and operational implications of such a process are anything but obvious and have been already discussed elsewhere.[17]
Secondly, color has been adopted as a visual key to facilitate the spatial and morphological understanding of underground settlements. The rock-cut architecture of Cappadocia is mainly the result of material subtraction from tufa hills, in general starting from natural cavities. The sculptural nature of this spaces makes them difficult not only to be understood but even to be represented, above all when compared to the traditional graphic and canonical models of architecture representation. While traditional architecture is based on the addition of elements, generally according to horizontal and vertical planes, rupestrian habitat is defined by rough and irregular surfaces that can be hardly reduced to few edges and straight

lines. Secondly, such architectures are mistakenly considered as only indoors, devoid of any relationship with the external environment and the other adjacent cavities.
To overcome these two operational and conceptual limits of the architectural graphic conventions, authors adopted a contour-line representation. Like for a topographic map, they entrusted a number of vertical and horizontal parallel planes the task of sectioning the numeric model and describing indoor architecture and ground morphology together. After some tests, the equidistance between these section planes was established in 10 cm. This step allows the contour lines to describe the architectural forms without becoming a sort of confused background noise by redundant visual data. Secondly, the distribution of the vertical section planes has been orchestrated to be the most convenient in describing the complex morphology of the carved settlement.
Finally, the color was applied both to the contour lines in the two-dimensional orthogonal projections (fig. 1d) and to the surfaces of the three-dimensional views after the meshed model (fig. 1e) in order to favor a more immediate reading of the horizontal and vertical relationships between the single hypogeal rooms, and between these and the external surface. The procedure for carrying out this type of representation consists of two main phases: transparency and assembly. The first step is to leave the sections empty and keep the background surfaces conceptually transparent in the orthogonal projections, in order to make the lower level lines visible. The second step is to divide the contour lines into groups referred to a single level and to assign them a different color.
In this type of representation, each color allows the reader to quickly identify all the rooms and corridors that share approximately the same altitude or depth with respect to the sectioning plane. At the same time, the succession of colors helps the reader to relate the environments with what is either above and below them, or before and behind them. Furthermore, the indoor spaces can manifest their natural continuity with the external surfaces.

4. Considerations on case studies

The three study cases present some conditions that are common to many others and some very specific aspects. Bernini’s sacellum is a case of reconstruction of a small-scale architecture, starting from a geometrically defined project, with a few inconsistencies and different questions related to some specific aspects of the “solid perspective” architecture that have been solved. However, it lacks any chromatic and material reference, excluding the statue actually built. The choice to carry out the reconstruction beyond the limit of the solid monochrome model, formulating conjectures both on the natural lighting system and, above all, by applying hypothetical materials to the main parts of the reconstruction is mainly linked to its role in the video displayed in the exhibition, and the needs of an engaging and dynamic communication aimed at a wide and untrained public.
The second case, although it is still an architectural reconstruction from a design, is very different. It is based on a drawing that is little more than a sketch, or rather, the meditated synthesis of a series of sketches on the same topic. Leonardo’s designs had the task of challenging the geometric and spatial potentialities of the centric

temple and have not taken the direction of a project for a specific site, with specific constructive and materials solutions. For this reason, a material mapping of the solid three-dimensional model could be conjectured only in the context of a precise location. A chromatic mapping is instead plausible by virtue of the adopted method – the diplomatic edition and the interpretative-critical edition – which requires a closeness to the formal, chiaroscuro and chromatic values of the original document.
In the third case, the model has resulted of a surveying activity that involved a single architectural complex. Here the color has been used to highlight the difference in altimetry of the various rooms belonging to the same level: a factor that cannot be represented in any other way. Contour lines and color have therefore allowed the simultaneous representation of the complexity of several functional levels linked together in a single monastic structure.

5. Conclusions

Digital models, especially the solid ones, are open and easy-to-manipulate structures and, thanks to the reversibility principle that pervades the digital domain, they can be treated with color and materials in the most different ways without being damaged.
The position of Leon Battista Alberti, according to whom the design concept needs a monochromatic model, devoid of color and decorations that can distract the beholder, finds an indirect confirmation in the black-and-white aesthetics of the developed in the early chemical photographic age. Thus, often chiaroscuro images without color and texturing look like suspended but encourage the observation of morphology, form, ergonomics.
Indeed, the color can be applied to models according to two main purposes, which are closely related to the modes of human perception.
1. color can contribute to present the model in ways that replicate the perception of reality. This is the case with the application of photographic maps or colors that evokes the visual experience of certain materials. This choice has the consequence of shifting the reception of the model on a predominantly sensorial and optical level, as required by the Virtual Heritage guidelines.
2. color can contribute to illustrate model properties that are not necessarily visible, such as syntactic properties between the constructive and stylistic elements or the topological properties between distant spaces. This choice, which allows to break down analytically and explain complex situations, shifts the reception of model on a predominantly mental and tactile level (which in the current “iconocratic” context demands the beholder for a greater attention).
In conclusion, one must remain critical, even in relationship with certain trends, which may dis-orient both specialized and non-specialized public. The case studies show that there is no valid formula for every type of digital model. Instead it is possible to find guidelines and answers not only within the criteria and objectives of the individual work but also within the historical and spatial characteristics of the object itself. Finally, the color itself can become a possible element of cultural connotation and enhancement of the documents and sites.

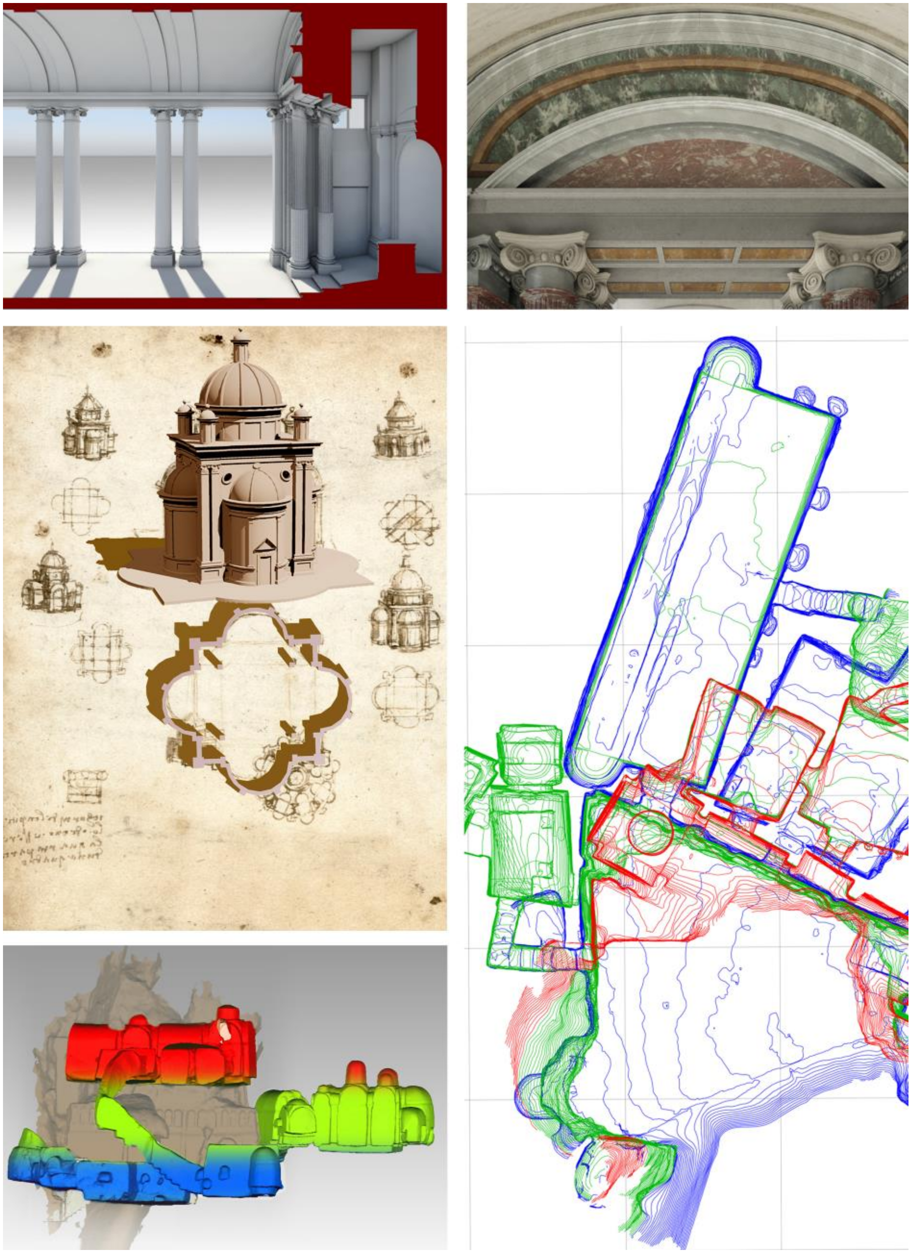

Fig. 1 – *Solid model of Bernini's sacellum*: a. view after monochrome model; b. view after material mapped model. *Solid model of Leonardo's centric temple*: c. view from the solid model. *Numeric model of Karanlik Monastery in Goreme*: d. colorful contour lines plan; e. view after meshed model.

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What we can learn about improving urban space from colour mapping

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1. Introduction

In this study, insights and practical recommendations are shared from Colour Your City projects that explore how colour influences us, and can be used to improve the built environment. Two projects have been selected: colour mapping and interactive art with artist Cydney Eva of PatternNation in Durban, South Africa and a large-scale mural space transformation in London, UK with artist Camille Walala. The methods deployed were field research, visual documentation, interviews and social art practice that invited responses.

Colour is a crucial factor in the built environment – which encompasses a wide range of building and infrastructure types, man-made and natural aspects, ephemeral artefacts, public artworks, squares and gathering spaces, devotional space, the spirit of place, the flow of humankind in constant transit, all kinds of entrepreneurial hustle, and the bustle of markets and commerce. Every complexly run system, simply present element and natural yet ceremoniously ordained 'canvas' in our city.

> "Empirical observations and scientific studies have proven that human-environment-reaction in the architectural environment is to a large percentage based on the sensory perception of colour ... human response to colour is total – it influences us psychologically and physiologically." F. H. Mahnke 2012 [1]
> "Colour is an important factor in environmental design. People think one is made happier by 'happy' colours and sad by dull colours." Sivik 1976 [2]

The call for good design of the built environment grows ever louder, especially with the future looking very urban indeed. By 2050 66% of the world's population will be living in urban areas [3]. With recent developments in cognitive neuroscience and cognitive neuropsychology proving just how important the environment is to the human experience.

> "Cognition is a product of a three-way collaboration of mind, body, and environment ... our minds and bodies – actively, constantly, and at many levels – engage in active and interactive, conscious and nonconscious processing of our internal and external environments." S. Williams Goldhagen [4]

Placemaking is an approach to public space that is gaining momentum around the world. Since 2011, the UN-Habitat (United Nations Human Settlement Program) has promoted the roll out of placemaking globally to help improve the quality of urban life and acheive sustainable urbanization. Placemaking aims to make public spaces into vital places that serve common needs, so they become well used and loved by citizens. The Project for Public Spaces in New York, are a nonprofit organization championing placemaking. Their *Place Game* [5], an observational tool to evaluate place performance, rates comfort, image and attractiveness as key indicators of what makes a great place. This is further evidence that how the built environment looks and feels matters. How our bodies and minds respond to it and what it communicates back to us is of importance.

Colour Your City believes in dynamic, energising, playful, fun and intriguing urban space. Colour Your City is a global movement dedicated to transforming and enriching urban space with colour. It invites people to regard their city as a canvas, and reimagine how it can be transformed with colour to energise urban space and better serve human wellbeing. Colour Your City produces site-specific transformations, researches the impact of colour in urban space, has an artist stable of colour-centric artists, and works with city shapers and makers to use colour consciously.

2. Method

2.1 Colour Your City x PatternNation – Durban, South Africa

Artists Cath Carver of Colour Your City and Cydney Eva of PatternNation partnered to colour map the coastal city of Durban in South Africa, and produce two interactive art installations in February 2018. The project also collaborated with Costa Besta and photographer and videographer NhlaNhla Gcabashe.

PatternNation is a collaborative visual art and design label aimed at connecting artists who embrace bold colour and pattern globally. Cydney Eva, who was born and raised on the unceded Coast Salish Territories of Vancouver BC Canada, is the founder of PatternNation and a visual artist, fashion and jewellery designer. The PatternNation aesthetic combines radical political views with playful and colourful interactive art.

For the purposes of investigating the impact of colour on urban space, colour mapping was utilised by taking photographs and videos on two walks to visually document the existing urban palette of the city. The route of the walks included a number of key areas such as prominent places of natural interest (the ocean and botanical gardens), hubs of commercial activity (CBD and street markets), residential areas and recreational space (public squares, monuments and the beachfront).

> "The act of walking… is to the urban system what the speech act is to language" de Certeau [6]

The installation comprised of three key elements: the first was a photographic exhibition of selected images from the colour mapping walks. Secondly, play sculptures – affectionately known as 'blobs' – made of upcycled fabrics joined together to create cloud-like shapes, were filled with balloons and interspersed around the installation site. The third element was a series of '#ColourChat' conversation cards each with a key question, blank space and pen for people to write their responses, and explore what connections they made between the city and colour, and how colour could be used effectively to improve the built environment. The questions were asked in an general manner, not referring to specific sites, to enable an open dialogue about colour and the city of Durban.

Sites

The installation took place at two sites with visitors mixed in their demographics:

1) **First Thursdays Durban** on Station Drive with Open Plan Studio
An art-focused monthly evening event with approx. 500 visitors predominantly aged in their 20s and 30s.

Fig. 1 - Installation on Station Drive.

Fig. 1 & 3 - #ColourChat respondents at the installation on Station Drive.

Fig. 4 & 5 - #ColourChat respondents and public playing with blobs at the installation on Station Drive.

Fig. 6 & 7 - Artists Cath Carver & Cydney Eva; installation on Station Drive.

2) **I Heart Market**

A monthly makers market held during the day, located next to the Moses Mabhida Stadium with approx. 750 visitors and many families.

Fig. 8, 9 & 10 - Public playing with blobs and responding to #ColourChat questions at I Heart Market installation.

Fig. 11 - Collaborator Costa Besta.

Fig. 12 - Artists Cath Carver & Cydney Eva.

#ColourChat
The conversation card questions were:

What are your colours of Durban?
Blue was the most popular response, closely followed by yellow, then green. Blue and green were frequently paired together, with references to the blue of the ocean and green forests. Orange, and purple (with reference made to blossom) were also popular.
There were also cultural references to the African continent, and flag of South Africa:
"Anything but dull. Lots of African colours everywhere."
"Blue, yellow, black, white, green, red – the SA flag"

How does colour make you feel?
Responses were strongly positive with the most common adjectives being happy, alive, excited and lit.
Other responses included: inspired, calm, at home, energy, happy, grateful, greatness, spicy, euphoric, tranquil, bliss, uplifting, vibrant, human, in love, magical, like a motherf@!%n rainbow, expressive, a part of reality, woke, beautiful, more comfortable with myself, different emotions, complete & vibrant, colours feel what I'm feeling.

How does colour improve attractiveness in the built environment?
Several references were made to adding LIFE and the response that exemplifies this best is "Brings life to the lifeless."

Other interesting responses related to:
SPACE DYNAMICS: "Makes it more intense and sensitive." "It creates warmth, brings life and community into otherwise dead space. Personality."
MOOD: "Makes it look happy." "It raises your mood." "Elevates the mind."
INSPIRATION: "Positive. Makes being in town inspirational." "Makes you feel inspired."
SMILING: "Makes you smile when you're in the city." "Puts a smile on my face."
INVITING: "Makes it inviting." "Welcomes."

Does a lack of colour effect urban space?
A unanimous yes! Several anti-grey references too: "of course, if you paint the walls grey the people will follow" and "sometimes greys and shadows are moody".

What is the one thing that would improve design of the built environment in Durban?
Greening the city featured strongly, with a common need for more vegetation including green roofs, plant walls and biomimicry. There was also desire for African-inspired architecture, restoration of the large Art Deco buildings that characterise the CBD, and colour under dark spaces.

How could Durban be reimagined with colour?
Murals and colourful walls proved very popular, including the suggestion that they be used as tools of social change: "Murals on walls near the beach front – symbolising important things that need attention by beautiful artworks, like plastic pollution." Public art was also welcomed in the form of "colour sculptures".
Using colour for culture and to highlight heritage was important: "Culture culture culture!"
The importance of colour was reiterated: "Colour = joy. Highlight our heritage." and "Durbs is so green compared to other places; colour signifies life!"

How should colour be used more around Durban?
"Colour should be abundant." and "put everywhere" was the general sentiment. There were also some imaginative ideas such as: paint roads in colour, use moss to add colour, use stickers, brighten up the beachfront, and make the sand blue with food colouring!

Which parts of Durban would you like to see with more colour?
Two keys areas stood out: the beachfront and the CBD. With other areas spread across the city getting a mention too.

What colour would you like to see buildings?
The most popular response was polychromatic. A highlight comment referred to the identity of South Africa itself: "Rainbow vibes. Like our nation."
Other strong colours were yellow, green, purple, blue and finally mentions of pink, black, indigo, charcoal grey & yellow, and metallic.
Other interesting quotes were: "psychedelic", "bright & happy", "street art", "pastels".

Do you have a specific Colour Story to tell?
A few choice stories that show colour connections come in so many ways:
"I wanna be happy like yellow."
"Green = ♥"
"'The purple shall govern' (purple symbolizes people)" – this is a fascinating example from South Africa's history books. It refers to the Purple Rain Protests, an anti-apartheid protest held in Cape Town on 2 September 1989. The police sprayed water cannons with purple dye onto protesters to mark them for later arrest. One protester turned a cannon on the police, spraying them purple too. The next day graffiti appeared with 'The purple shall govern', a clever play on 'The people shall govern' from the Freedom Charter. [7]

What is your experience playing with the blobs?
People clearly had a great time playing with the blobs, which could be swung, gently batted or simply enjoyed as a visual feast of colour, pattern and textures:
joy, fun amazing, awesome happy, wow, happy, I love it, I feel inquisitive.
"Shape, colour, form, feel – inspires my senses."

Several film interviews were also conducted:

What are the colours of Durban?
Surfers: green (vegetation) and blue (ocean)
Sand sculpters: blue (ocean)
Tourism KwaZulu-Natal employee: yellow (represents the beach, is bright and a welcoming colour, also used in beadwork, and the uniform colour of the tourist board!)

2.2 Camille Walala x Colour Your City x Well Street, E9 – London, UK

Colour Your City partnered with French-born, London-based artist Camille Walala, and Well Street Market, E9 to transform a prominent corner facade in the London Borough of Hackney. It was painted using spray cans and pots of paint in November 2016.

The artistic intervention was a collaboration with Well Street Traders and Residents Association (WESTRA) to improve and beautify the street in preparation for a new street market. Volunteers from the local community helped paint the artwork too.

Fig. 13 - Before site transformation.


Fig. 14 - After site transformation.

Members of the public interviewed afterwards to assess the impact of the artwork gave incredibly positive feedback:

"Nice to come down and not see everything so drab and dull. It catches your eye. It's the first thing you look at. Love it."

"Places that look rundown and depressing, it brightens them up. Something nice to look at, even if it's for a few seconds while you're walking. It makes it more of an interesting walk down Well Street."

"Vibrant colours. To be honest it looked very ugly before. Now it looks very good."

"Colour is huge. To be able to have somewhere that is disused and has that derelict feel, and to be able to transform that. It could be happening all over London. It's an injection of energy. It's beautiful. I love it."

Everyone spoken to welcomed the change and felt it had improved what was commonly perceived as an eyesore – derelict shop fronts left in a state of disrepair for years – into a vibrant and cohesive work of art using Walala's signature colourful and bold 'tribal pop' patterns.

The site had pictures taken before and afterwards, and a short film was made to document the transformation:

www.youtube.com/watch?v=ki7Y5CfcvDA

3. Results and Discussion

The colour mapping walk in Durban was found to be a very useful way for the artists to 'hit the streets', get to know the city well, document its existing colour palette and help set the context for the project. Exhibiting selected images around the installation site was a valuable added attraction to the blob play sculptures. The photographs also served as a visual stimulus and conduit into the colour chat, to remind respondents what was in the city already, prompt what they might like to see change and help spark conversations. This combination of imagery and conversational questions worked very well, and perhaps led to more thoughtful responses by 'bringing' the wider city to people in that moment. There is also the possibility that the images could have influenced responses too, by focusing attention on the places in the images.

Due to the public and porous nature of the installation sites, it was difficult to track visitor numbers, respondent numbers and demographics, so it doesn't enable a thorough analysis of the data from that perspective. Perhaps future research can include more traditional closed surveys as well, which would solicit demographic data and enable more accurate tracking of participant numbers.

It is also likely that the self-selecting respondents were engaged, curious and motivated to answer the questions, meaning the results will be somewhat skewed by proactive people with something to share. However this type of openness does have the advantage of being very easy and simple to participate, making it an accessible tool of public discourse about city design.

It was interesting to note that people of all ages including children – especially at I Heart Market – were keen to share their views. People enjoyed reading other responses too, which incidentally could have socially influenced what they then shared themselves, by being inspired or moved by what others had written.

Curiously in several cases social media handles were written alongside answers, suggesting that people saw the cards as an opportunity to boost their personal profiles, in an age of relentless self-promotion and networking. The ubiquity of hashtags – sliding into offline / common parlance realms – was evident with several uses, such as #lit.

In terms of the content of responses, there was unanimous sentiment that colour engendered positive feelings, and enhanced city attractiveness by making it feel more alive, inviting and uplifting. People predominantly identified the colours of Durban as blue for the ocean, green for the forests, and yellow for the sunshine, brightness and beach. This shows just how connected we are to the colours of nature, as vast and apparent environmental elements.

Insights into how to improve urban space included adding more greenery to the city from green roofs and walls to biomimicry, purposeful art such as murals with social messaging, multi-sensory art, polychromatic building facades, and using colour to celebrate culture and heritage.

There was a desire for restoration of the large Art Deco buildings that characterise the CBD and have historically been bright pastel colours, many of which are currently in a state of disrepair and neglect. The CBD in general and the beachfront were two areas of high usage and considerable desire for more colour and attention.

Standout responses were:
"If you paint the walls grey the people will follow."
"Colour makes me appreciate the world for its beauty."
"At the moment things are very concrete, and also kind of lifeless. Curves, colours and shapes add to it, they bring more life and feeling."

The variety of responses also demonstrated the far-reaching nuances that colour possesses: from the South African national flag, to matters of identity as a 'rainbow nation', proud geographical rooting within the continent of Africa, and specific historical events such as the Purple Rain Protests during apartheid.

With the second case study, the Walala large-scale mural in London, the feedback demonstrated that changing the aesthetic look of the corner facade from derelict shops to a bold and brightly colourful design had a strong positive impact on the community's daily experience walking past it. This shows the power of art to flip environments from tatty eyesores to sources of beauty, interest and delight.

In future there could be a quantitative survey utilised as well, to help measure and communicate impact as well as qualitative responses.

4. Conclusion

As architecture critic and champion for better city design, Sarah Williams Goldhagen, puts so well in her book "Welcome to Your World", it is high time for much greater awareness about what constitutes good design in the built environment:

> "The more we learn about how people actually experience the environments in which they live their lives, the more obvious it becomes that a well-designed built environment falls not on a continuum stretching from high art to vernacular building, but on a very different sort of continuum: somewhere between a crucial need and a basic human right." [8]

Conscious colour use has to be part of the good design equation for city makers and shapers, and there are so many ways to use it to serve wellbeing.

> "Colour's unique contribution, if applied intelligently and sensitively, cannot be obtained through any other means." F. H. Mahnke [9]

It is clear that colour is a powerful tool of creativity, design, communication and connection, vital to understanding ourselves and the world around us. This research demonstrates a clear human need and desire for more colour in the urban environment, and the huge creative potential there is for using it in imaginative and uplifting ways.

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7. Colour and Design

Simulated CMF as a Credible Representation Method for Experimental Design Studies

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1. Introduction

Colors, materials and finishes (CMF) is a vital component of many branches of design, including architecture, interior design and product design. In professional design practice and within design research, the use of digital representation tools is commonplace, although their application in CMF decision-making has not been formalized. Three-dimensional modelling tools excel at the definition and evaluation of form and spatial arrangements. They are frequently also used to create photorealistic visualizations of surface material properties (e.g. to explore material families, textures, reflectance, colors etc.). Despite the technological advances of digital tools, a significant number of designers still have a preference, wherever possible, to use physical samples of materials in their design processes. The tangibility of samples provides a real-world assessment of material properties that cannot (yet) be satisfactorily replaced through a digital representation. Nevertheless, material samples can be expensive and time-consuming to source, and relatively cumbersome to archive and retrieve.

In the context of contemporary environments, colors are more complicated, subtle and influential than perhaps at any time before. That is why the fundamental article of Umberto Eco, which is entitled ‘How Culture Conditions the Colours We See’, started with the phrase: “Colour is not an easy matter” [1, p. 157]. In a similar way, the materials of contemporary design are also complicated: diverse, multimodal, and serving both practical and expressive roles. According to Karana (2009) all living creatures and non-living things are sharing materials as a common point [2]. Materials affect not only the physical appearance of interiors and designed artefacts, but crucially they affect people’s perception of those interiors and artefacts. Colors and materials – usually extricably linked elements of a design – have fundamental effects on perception and experience. Previous studies have investigated these effects in a variety of design contexts [3, 4, 5, 6] and demonstrated how colors contribute to design-designer and design-user relationships [7]. The opportunity, therefore, arises for investigation into how effective different representation methods of CMF can be in the pursuit of improved interiors and designs.

Taft (1997) suggests a good match between 13 colored chips and single hue colored images of 6 products, however, there are differences depending on product type, color hue and semantic scale [8]. Van der Voordt et al. [9] highlighted the importance of representation methods of colors during experimental design studies, which could affect how transferable the results are into real world conditions. The aim of the research presented in this paper was to make an initial investigation to establish the credibility of using simulated CMF as an effective substitute for tangible material samples. More specifically, within the context of experimental design studies, the research sought to assess whether a hybrid representation method (CMF digital images projected onto a neutral physical surface) could be a valid alternative to using real material samples. A positive outcome would open the possibility of a more convenient and agile method of material evaluation for designers and researchers across the design disciplines.

The representation of color has been transformed during recent decades in parallel to improvements in color science, image science, etc. and has promised new horizons [10]. Researchers have been working to improve lighting quality of digital models across disciplines, especially to bring real-time processing of surface reflections from different points of view [11, 12]. It might be anticipated that CMF properties will be represented on-screen in ever more sophisticated ways and to better resolution and quality in the coming years, especially in relation to real-life external lighting conditions. This where a principal challenge remains, in that there is always a gap between the real-life experience of an interior space or physical product and the experience of the same designs represented using digital tools. Color, lighting and material properties if handled poorly in a digital environment can create a gap between visual predictions of a design and how it will actually be experienced when materialized. The exploration and proposition of more advanced digital simulations – specifically targeted at reducing this gap – is, therefore, something broadly welcomed in the context of design.

2. Experimental Set-up

The experimental work was conducted within the context of interior architecture. Two different interior CMF representations were compared across two independent studies: study 1 involved a physical material-based representation, whilst study 2 involved a simulated material representation. Validation centred around a hypothesized absence of statistically significant differences between the two representations, based on directly comparable materials perception data generated from both studies.

Sixty (60) voluntary participants were sourced for the experiments (30 each for studies 1 and 2) and a gender balance was achieved for both cohorts. All participants were either undergraduate or graduate students, having a good foundation of design knowledge as students within Bilkent University, Faculty of Art, Design, and Architecture. The experiments were conducted in Turkish within the facilities of the same Faculty, in Ankara, Turkey.

An Ishihara color-blindness test was applied for the sourcing of volunteers. Those who could not pass the test were declined participation in the experiments. Participants who had eyesight deficiencies were asked to use their corrective contact lenses or glasses during the experiment. Data were generated from a single questionnaire administered for both studies.

Section 1 of the questionnaire requested demographic information (including academic department, gender, etc.), whilst section 2 requested visual perception responses to the CMF stimuli, specifically the degree to which the stimuli affected participants' feelings (against three 7-point semantic differential scales for 'warm', 'energetic' and 'intimate'). The scales were consistently constructed with '1' representing the lowest level (e.g. very cold) and '7' representing the highest level (e.g. very warm). In both studies, participants were instructed to make visual evaluations only; in study 1 participants were not permitted to touch the physical samples.

2.1. Study 1

For the material-based representation, a fabric (100% cotton) was painted with Sirca CT5503 water-based paint. After painting and drying, the fabric was measured by NCS Color Scan 2.0, registering a surface with S 3070-Y90R NCS code. This color was preferred because of its attention-grabbing nature. The paint was chosen because its water-based formulation would protect the natural surface properties of the fabric after painting. In contrast to some other fabric types that include plastic additives causing glare on the material surface, the 100% cotton fabric exhibited no such glare. The fabric was wrapped around a scale model (measuring 20cm by 41cm) of the corner of an ordinary room.

An experiment box (40cm height, 50cm width, 50cm depth) with an open front was used to exhibit the scale model (see Figure 1). A Philips TL-D 90 Graphica 18W 965 - 59cm (MASTER) lamp, which ensures accurate color viewing conditions, was fixed to the center of the top surface to provide homogenous illumination within the box's interior and on the surfaces of the model. The experiment was conducted in a darkened room without any windows or natural light. During the experiment, the lamp in the experiment box was the only lighting in the room. Whilst completing section 1 of the questionnaire, participants were provided time to adapt to the lighting conditions prior to exposure to the model. Each participant sat in a chair located at the open front of the experiment box. An instruction was given to imagine the model as a corner of an ordinary interior space covered with red fabric, and then to evaluate the material/color combination using the scales in the questionnaire. The same methodology can be found in a previous color study [13] and is extracted from the first author's doctoral dissertation [14].

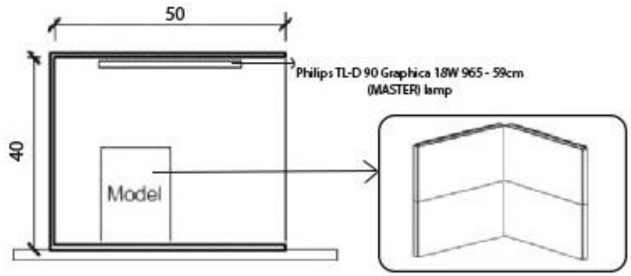

Fig. 1 – The section of the experiment box with the perspective drawing of right angled model [14]

2.2. Study 2

For the simulated material representation, the same red fabric used in Study 1 was optically scanned as a JPEG digital image file using a HP Officejet 7500-A Wide Format device. The JPEG was then projected onto the corner walls of a white room using a Sony Data Projector (Model No: VPL-EX 100), creating a simulation as if the walls were actually covered in the red fabric. Importantly, dimensions and viewing distance were calibrated to reach comparable proportions – from participants' perspectives – to study 1 (see Figure 2). All windows within the room were covered so as to block the ingress of natural light. Mirroring the protocol of Study 1, participants were accepted into the room on an individual basis and sat in a chair fixed oriented towards the join of the corner walls. An instruction was given to imagine the projected image as a corner of an ordinary interior space covered with red fabric, and then to evaluate the material/color combination using the scales in the questionnaire.

Fig. 2 - Experimental conditions for the simulated material representation method [14]

3. Results

The mean and standard deviation values for the six experiment conditions (2 representation methods x 3 semantic scales) are provided in Table 1. A Wilcoxon Single Rank Test was used to analyze the results with IBM's SPSS Statistics 20 program (see Table 2). The null hypothesis was that the two representation methods would generate results with statistically insignificant differences. This was found to be the case for the 'warm' and 'intimate' semantic scales. However, for the semantic scale 'energetic', the two representation methods yielded differences in results that were statistically significant.

	Material-based representation method	Simulated material representation method
Warm	5.33 (1.26854)	4.8 (1.42406)
Energetic	5.16 (1.51050)	4.03 (1.68293)
Intimate	4.26 (1.92861)	4.06 (1.84274)

Tab. 1 – Mean and standard deviation values (in parenthesis) of semantic scale results for material-based representation and simulated material representation methods

	Comparison of semantic scale data: material-based versus simulated material representation methods
Warm	Null (,054)
Energetic	Rejected (,012)
Intimate	Null (,544)

Tab. 2 – Statistics test results for the two experimental conditions (Wilcoxon Single Rank Test)

4. Discussion and conclusion

In this study, a partial validation of simulated CMF being equivalent to physical material representations was achieved, based on the metrics of 'warm' and 'intimate'. Validation though the metric of 'energetic' was not achieved. The experimental stimulus in study 1 (material-based representation method) was found statistically to give a larger 'energetic' effect on users than the stimulus in study 2 (simulated material representation). That might be a result of different degrees of immersion (model vs. life-size) or color vibrancy (paint pigment vs. light projection) between the two studies. Similar to the partial validation of the current study, previous research [8] has shown that two different representation methods (colored chips and single colored objects) affect semantic scale assessments differently. For instance, a 'feminine-masculine' scale yielded the same results for both representations, whereas 'beautiful-ugly' did not [8].

The partial validation of simulated CMF was achieved in the context of interior architecture / design, using plain corner walls as the point of design interest. This result is encouraging and shows the potential for digitally augmented surfaces to be used not just notionally but effectively as visual replacements for real material samples. The results in this paper will give confidence regarding the validity of such experimental set-ups in future design studies. For interior and exterior architecture, the potential to set up immersive – or at least full-scale – simulated CMF mockups for evaluation purposes can quicken design decision-making processes. Similarly, for product design portable CMF projection onto smooth neutrally colored surfaces of a physical model could offer designers a very quick tool for testing multiple CMF schemes within a realistic usage context. However, a major challenge for the realm of product design is the complexity of curvature and form features in products, compared with the relatively planar surfaces of interiors. Furthermore, for visually/tactually complex materials (e.g. pronounced wood grain, perforated metals, etc.), the illusion of three-dimensional surface properties should be highly convincing for the simulation to be successful.

The mixed reality (real wall + projected CMF) of the simulated material representation method is its critical and worthy feature and the findings presented thus far justify further investigation of simulated CMF as a potentially credible representation method for experimental design studies. Certainly, the mixed reality of the method offers spatial and 3D presence advantages over placement of conventional digital representations of interior scenes and products rendered on 2D displays (monitors, TVs etc.). Furthermore, the use of physical material samples is an expensive and demanding process, and within a research context the difficulties in preparing and using CMF properties on real materials should not be underestimated.

Future studies might involve a larger number of semantic scales, a variety of CMF properties, and different foci for design applications, such as interior fixings, furniture, and consumer products. In addition, VR (Virtual Reality) technologies should be compared to the existing methods as a promising CMF representation method taking into account constantly variable user POVs (points of view).

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Enhancing Co-responsibility for Environmental Protection by Designing Colorful Spaces Inspired by Nature

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Abstract

In the words of Ahmad Shamlou, Iranian poet: "I was born in hue of us, in glorious hue of Human Being, born as a human means embedded responsibility." It describes human as a co-responsible being and refers us to Heidegger quote, "being in the world is always also being with the world." In other term, the 'co' is always hidden in responsibility. Co-responsibility conveys interwoven responsibility between several paradigms or people.

Furthermore, human and nature symbiosis has embedded human's inclination towards nature in their implicit memory. At the present time, dwelling in achromatic built environments led to negligence of environmental protection. Environmental protection is a series of practices protecting natural environment by individuals, governments and organizations. Overpopulation, overconsumption and unwise usage of technology cause inevitably environmental degradation. In this situation, human ought to recall his co-responsibility.

Designers should also contribute to sending this message of environmentalism to the world. To this purpose, color is defined as an impressive means. It extracts embedded memories of other times and spaces. This cognitive process occurs mostly unconsciously or subconsciously. Remarkably, early 1990s recession in USA warned people about consequences of omission of nature. It propelled people and designers to revive colors signifying nature like green. The aim of this study is designing a space to enhance co-responsibility of inhabitants of urban area and encourage them to be an active environmentalist. In order to achieve this objective, we will design 6 types of form in several colors inspired by nature, modernism and industry to investigate which one evoke people to protect environment. The result of this analytical study will apply in designing of space.

Keywords: Design; Environmental Protection; Co-responsibility; Nature; Color and Form.

2. Literature Review

2.1. Co-responsibility

As mentioned above, focus of this article is on one the most important issues of today, environmental protections. Human beings seek habitually accountability. People want to know who is responsible for certain actions and who is accountable for the consequences of those actions [3]. Iranian citizens, mostly, hold the government responsible for environmental issues. However, it looks, these problems are results of their activities; and in fact our activities. In this situation, we should to consider ourselves as a responsible whole.

Vincent E. Barry has defined the term *responsibility*, as referring to “a sphere of duty or obligation assigned to a person by the nature of that person’s position, function, or work” [3]. But, as French philosopher Jean-Luc Nancy a few years ago said, it means: ‘‘the anticipated response to questions, demands or interpellations which are not yet formulated or exactly foreseen’’. So, it is fundamentally to be involved in social relationships, to be in common and never merely to fulfill only the obligations or duties [4]. Consequently, the concept of "co-responsibility" will be developed. The term "co-responsibility" describes how individuals, despite the fact they are responsible for their own agency, are always also affected by a requirement which contaminates their efforts to fulfill their duties and obligations [4].
The hegemony of binary thinking leads to conflict between individual and social. As Friedrich Hegel pointed out: neither individual (thesis), nor social (antithesis) but shared responsibilities (synthesis) [4]. "co-responsibility", however, is more than this synthesis.
In the state of being co-responsible, individual and social are, indeed, closely interrelated with each other. Martin Heidegger in Being and Time describes da-sein as a specific experience of being in the world. Because Being is not conceived of as a thing, but as that which ‘transcends’ things. What is special about humans is that they are capable of being here, in a situation, in relation to other things. He also believes that Da-sein stands in relation to Being itself, but that this relation is usually veiled by our everyday mode of relating to things in the world. Heidegger defines the being of da-sein or being-there as exclusive of the body [5] [6]. the ‘there’ means that no individual can place him- or herself over and against the world. Rather, the world is the horizon to which every individual existence is always and already related. Therefore, being-there in the world is always also being-with the world. In other words, existence is always co-existence. We have formerly discussed that When we talk about responsibility, the ‘co’ is always at stake. Co-responsibility means that responsibility is never me or the other’s, but the intermingling of the other’s and me, not in the way that they are shared, but that they intrude or contaminate one another [4]. To hold you co-responsible is to hold you to account for the group’s act in virtue of the features that makes you a member of the collective agent [7]. As Henry ford said: " Coming together is the beginning, keeping together is progress, working together is success." Being together suggests a way of dealing with people with respect to highlight individual group members' abilities and contributions. There is a sharing of authority and acceptance of responsibility among group members [8].

2.2. Environmental protection

If the environment is “everything that surrounds us”, then its imminent collapse should be a reason for serious alarm among all members of our species [9]. Pooran Desai has in *One Planet communities* written: "The sixth great extinction is on the way, that is due to the irrational attitude, behavior and habits of humankind. The solution to this crisis is sustainable development, that should not only be considered as a philosophy of thought and slogan, but as a policy and action, which should be addressed to all sections of society, to all people. Sustainable development is described in 3 pillars, i.e. economic, environmental and social. This has been recently expanded by some authors to include a fourth pillar of culture, institutions or governance [10].

As it is often said in sustainability circles, when the environment collapses, everything collapses [9]. The environment, indeed, is the complex set of physical, geographic, biological, social, cultural and political conditions that surround an individual or organism that ultimately determines its form and the nature of its survival. It also influences the way people live and the way societies develop. The pressures on the world's environment are numerous and come from diverse sources [9]. Various human activities have induced many undesirable effects to the environment which can be threatening human health, economic, natural resources and gene pool of ecosystems such as pollutions, greenhouse effect, global warming and soil erosion [11]. Natural resources, land, water, forests and various animal species are being degraded or lost at an alarming rate in many places throughout the world. The reasons include poverty, greed, untenable economic models, mismanagement of resources, lack of adequate education and trained personnel, under-development, deforestation, illegal dumping of hazardous wastes, global warming, the depletion of the ozone layer, pollution and many more.

Essentially, an over-emphasis on economic development without environmental system considerations lie at the heart of why our planet's environment is in such peril [9]. On the other hand, contemporary political rhetoric to the contrary, the prevailing growth-oriented global development paradigm is fundamentally incompatible with long-term ecological and social sustainability [12].

Raising public awareness is essential to protect environment. It is of utmost importance that the people should be aware not only of the problems involved but also of the role to be played in protecting the environment [11]. Environment and education are, in fact, both vital elements of human existence that can be used to enhance the quality of the human condition. The environment provides the space and essential ingredients for life where humans are able to interact with each other, with the infrastructure and with the environment itself. On the other hand, education is the process and result through which teaching and learning operate. Through this process, knowledge, values, attitudes and skills are imparted to the learner [9]. In the words of Oscar Wild: "learning is the most valuable thing that can be educated." Many learning experts believe that effective education is simple as given people the tools and opportunities to learn, and then staying out of their way. This approach makes them a stakeholder in their education, giving them a greater locus of their control and a greater sense of purpose [13]. On the other hand, this autonomous manner of learning through corporation, informal interaction and action lead to recall human memory and collective human memory.

2.3. Implicit memory

Each individual possesses embodied skills and inclinations, which termed body memory. This memory is of a kind quite different from the episodic memory by which we recollect and represent the past as such. Through repeated and typical interactions with others -such as nature, culture or people- an individual intention is formed, and with it the norms and rules of nature and culture are inscribed into the body, yet in

such a way that the resulting memory corresponds to an embodied and implicit knowing *how*, not to a knowing or remembering *that* [14].
As Juhani Pallasmaa in *The Thinking Hand: Existential and Embodied Wisdom in Architecture* describes: " Human being as a physiological entity has coexisted with nature for a long time. This symbiosis and interaction with nature has embedded inclination towards nature in human's implicit memory. Since philosophy has developed in ancient Greece, rationalism is considered as a highly significant attribute of homo sapiens. Human being reacts to the world, however, immediately, emotionally and unconsciously" [15]. These reactions, mainly, have root in human's implicit memory rather than explicit memory [16]. That is revealed when previous experiences facilitate performance on a task that does not require conscious or intentional recollection of those experiences [17]. The first clear reference to an implicit memory phenomenon appears to have been made by Descartes in his 1649, in which he observed that some aversive childhood experience may "remain imprinted on his brain to the end of his life." In 1704, Gottfried Wilhelm Leibniz developed a systematic doctrine that both allowed for and made reference to implicit memory. The first philosopher after Leibniz to discuss phenomena of implicit memory was Maine de Biran. Various 19^{th}-century philosophers concerned with unconscious mental processing such as William carpenter and Ewald Hering. Toward the end of the 19th century, systematic empirical and theoretical analyses of implicit memory emerged in five different areas: "psychical" research, neurology, psychiatry, philosophy, and experimental psychology. The richest sources of implicit memory phenomena were made by Claparele, Freud, Janet, Korsakoff, Prince, and others [17]. Researches about implicit memory have continued up to now.

2.4. Color in Built Environment

Color, which is the reflective performance of light on different materials, makes the world colorful [1]. People get refreshing feelings as well as restless mind because of different colors [2]. However, it is considered secondary to building form and structure, reflecting attitudes held by many design professionals since the renaissance [1]. Aristotle established the rationale used in the 'designo versus colore' debate during the renaissance. In 1911, le Corbusier influenced attitudes toward color in design that are still held today [1]. Since that time, the approach of color moved from the experience of Avant-garde paintings to the applied arts, architecture and public art [18]. The De Stigl movement in 1920s and color imaginary in the Post-modern movement in 1980s followed le Corbusier's view. The statue of color in architecture and environmental design as a primary role is still debated [1].
Color is described in various ways. It can be seen, but cannot be touched; it is a natural material, and it is assimilated by the civilization; it has no weight, but it is able to shake peoples' hearts. Colour is like free air, and it does affect our lives all the time. The colors of plants and pavements will bring people the feeling of excitement or tranquility. The colors of the surrounding will arouse different feelings in people with the change of the quality of the color [2].
Functions of color in the environment can be classified into 3 categories:

- Psychological function: Color not only affects the sense of beauty, but also has an impact on people's emotion and the efficiency of living and working. Researches have proved that color has cognitive effects and also impact on human mental health. There are a lot of fresh cases to prove that urban color has an effect on the urban residents' psychology.
- Physical function: Color is the most important part of urban beauty, and it is also an important factor in the quality of urban residents' life [2].
- Cultural function: The phenomenon of color that carries semantic, emotional and aesthetic information is called the cultural function. The boundaries of the cultural function define the epoch and geographic frame in which it exists [19].

Human, both designer and user use color based on his life-experience: in the context of his natural, material surroundings, way of life while concurrently relying on symbolism of color – the collective experience of the past generations. Historical documentation survey, aesthetical and psychological approach generated their expression within architectural color interpretation.

The factors that affect forming of the colors structures in public urban space are:

- Relation of the form and the color of the public urban space
- Natural – climatic characteristics of color
- Perception of the public urban space form through cultural identity of the surroundings [18] [19]
- Optimal and tactile perception of the surroundings [18]

3. Research objective and methodology

3.1. Research purpose

In early 1990s when recession in USA brought about omission of nature and environmental problems, designers figured out potential of colors signifying nature to encourage residents being and thinking green [20].

As it was pointed out, one of the aims of this research is to survey how colors and forms in built environment affect protecting environment. We intent to identify which colors and forms can better remind residents to be co-responsible to environment and persuade them to be an active environmentalist.

For this purpose, we designed 3 completely distinct forms (see Fig. 1):

- Form (1) inspired by Egyptian pyramids as a symbol of civilization
- Form (2) inspired by George Pompidou center as a symbol of modernism and technology
- Form (3), a curved and amorphous form addressing the nature

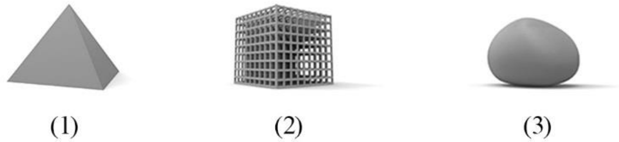

Fig. 1 – 3 distinct forms to investigate which one recall sense of co-responsibility to environment.

As Fig. 2 indicates, we chose 5 different colors:

- Color (1) / Red: This color is visible in some natural elements such as flowers, fruits, animals and etc. But it mainly refers to social, cultural and religious customs and elements.

This color is symbol of danger, ceremony, joy, enthusiasm and sacrifice [20] [21] [22].

- Color (2) / Khaki: This color can be seen in natural elements such as soil and animal but it mostly associates with ancient, historical, cultural and military elements [20].
- Color (3) / Purple: This color is rarely visible in some natural elements such as flowers and fruits and it is considered as an artificial and unconventional color.

This color has mainly semantic function. It is symbol of royalty, piety and ambiguity [20].

- Color (4) / Blue: This color is remarkably associated with nature and can be widely seen in nature. It has also cultural, religious meaning.

This color is symbol of divinity, harmony, nature, serenity and truthfulness [20] [21] [22].

- Color (5) / Green: Most people imagine green when they think about nature.

This color is symbol of nature, life, peace, fertility, safety and freshness [20] [21] [22].

It is, however, clear that colors have distinct meanings in different cultures. What, was mentioned above, is a general and universal concept of each color.

(1)	185C	50	76	42	234	4	55	#EA0437	
(2)	721C	76	17	29	229	174	134	#E5AE86	
(3)	2592C	37	62	-55	144	22	178	#9016B2	
(4)	2728C	33	20	-69	0	71	190	#0047BE	
(5)	382C	80	-25	88	182	211	0	#B9D300	

Fig. 2 – 5 distinct colors to investigate which one recall sense of co-responsibility to environment.

3.2. Research Methodology

This study is included in category of quantitative research. Its result can be applied in field of design and lead to positive consequences in social, political and health field.

On the other hand, designers encounter always with a lot of qualitative data that makes design process and evaluating difficult and prolonged, this kind of quantitative data can be defined as useful.

3.3. Research Method

First of all, we reviewed literature then we designed a computerized and self-completion questionnaire to collect primary data. The questions were closed-ended. Responses were graded on a scale from 0 to 5 -with 5 strongly agree and with 0 strongly disagree-.

The question was, " Does the following image make you feel responsible for protecting environment? Please rate." We asked people to respond based on their first impression. This question was repeated for 15 images (see Fig. 3):

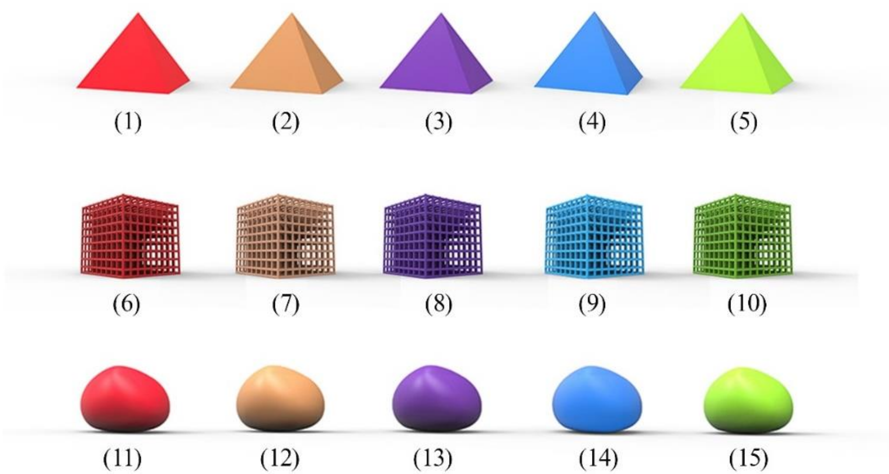

Fig. 3 – 15 distinct images to investigate interrelation between form and color and to recognize which one recall sense of co-responsibility to environment.

3.4. Date Collection

103 respondents completed this questionnaire.

Fig. 4 indicates, rate of preference for image (1) is 159.

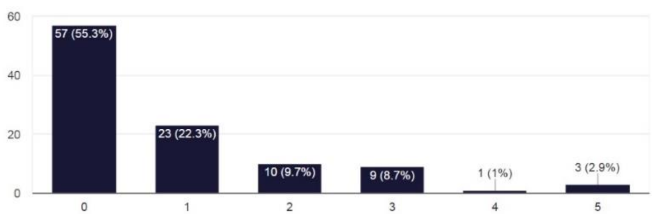

Fig. 4 – rate of preference for image (1).

Fig. 5 indicates, rate of preference for image (2) is 139.

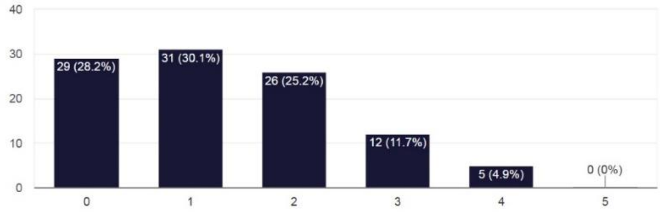

Fig. 5 – rate of preference for image (2).

Fig. 6 indicates, rate of preference for image (3) is 77.

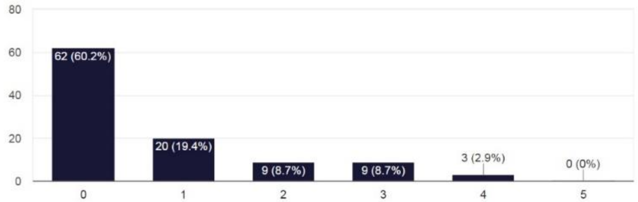

Fig. 6 – rate of preference for image (3).

Fig. 7 indicates, rate of preference for image (4) is 241.

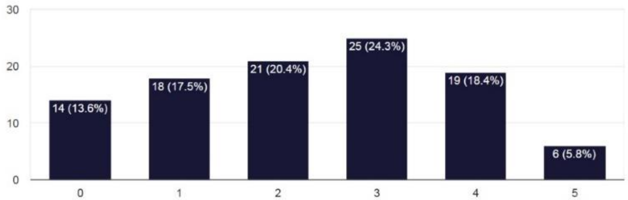

Fig. 7 – rate of preference for image (4).

Fig. 8 indicates, rate of preference for image (5) is 311.

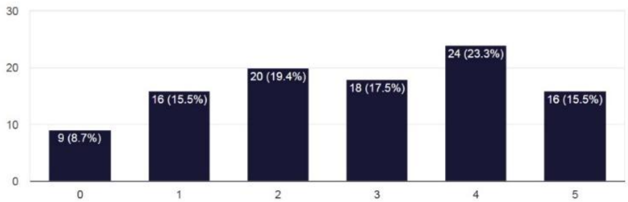

Fig. 8 – rate of preference for image (5).

Fig. 9 indicates, rate of preference for image (6) is 88.

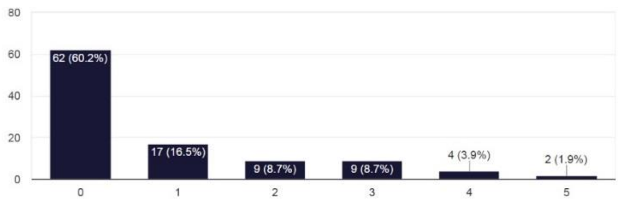

Fig. 9 – rate of preference for image (6).

Fig. 10 indicates, rate of preference for image (7) is 108.

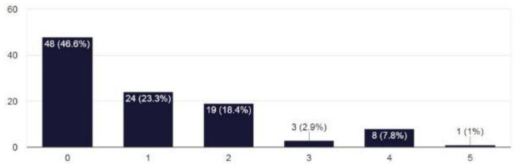

Fig. 10 – rate of preference for image (7).

Fig. 11 indicates, rate of preference for image (8) is 61.

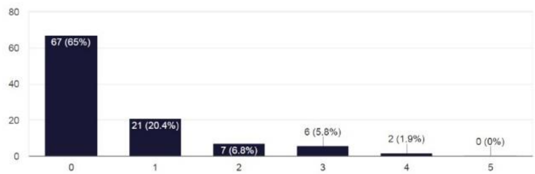

Fig. 11 – rate of preference for image (8).

Fig. 12 indicates, rate of preference for image (9) is 176.

-Unfortunately several respondents reported they had a problem with this image, because of that they rated this as strongly disagree. -

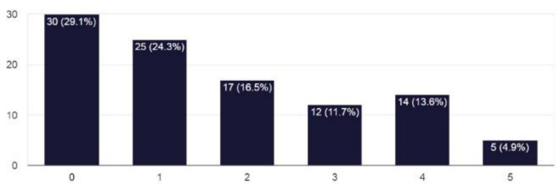

Fig. 12 – rate of preference for image (9).

Fig. 13 indicates, rate of preference for image (10) is 287.

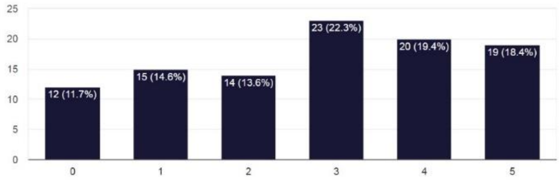

Fig. 13 – rate of preference for image (10).

Fig. 14 indicates, rate of preference for image (11) is 80.

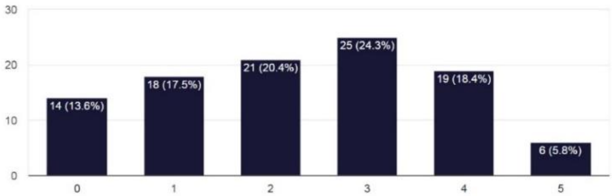

Fig. 14 – rate of preference for image (11).

Fig. 15 indicates, rate of preference for image (12) is 121.

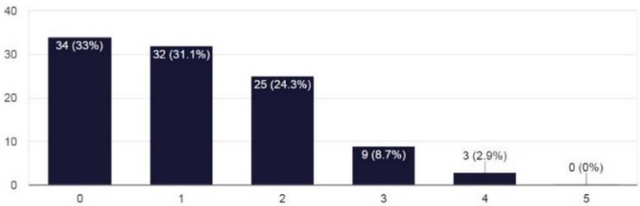

Fig. 15 – rate of preference for image (12).

Fig. 16 indicates, rate of preference for image (13) is 64.

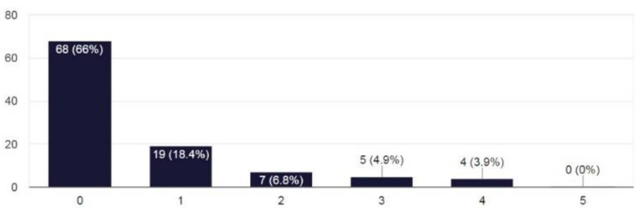

Fig. 16 – rate of preference for image (13).

Fig. 17 indicates, rate of preference for image (14) is 233.

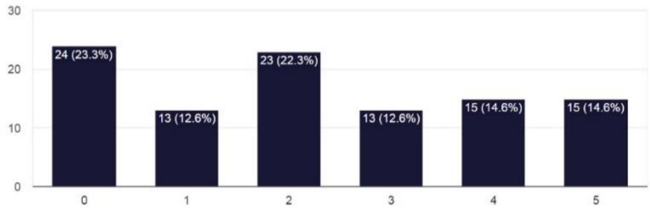

Fig. 17 – rate of preference for image (14).

Fig. 18 indicates, rate of preference for image (15) is 262.

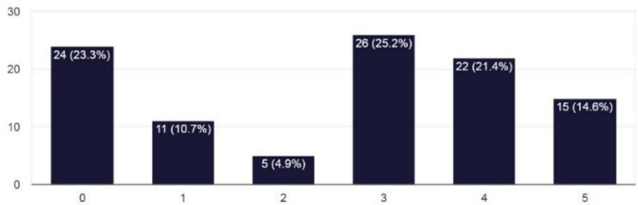

Fig. 18 – rate of preference for image (15).

3.5. Research Result

Result of this survey shows that color has a *remarkable* impact on the way citizens feel themselves responsible for environment. However, *sufficient attention is not paid* to color choice in design process. People usually depend on their sense of sight in an environment, and color is usually the first thing to "see" [16]. But it is frequently discussed as a secondary factor in environment design.

As shown in Fig. 19, when various colorful forms were compared with each other people were influenced by colors rather than forms. As a consequence, regardless of whether form is inspired by natural form or not, color blue and color green symbolizing nature, could better make people feel themselves responsible for protecting environment. Color purple that can be seldom seen in nature, is the least influential on people to remind them be responsible to environment.

At first glance, color red and color khaki are not also considered as colors that can make people responsible to environment. However, they are frequently found in nature.

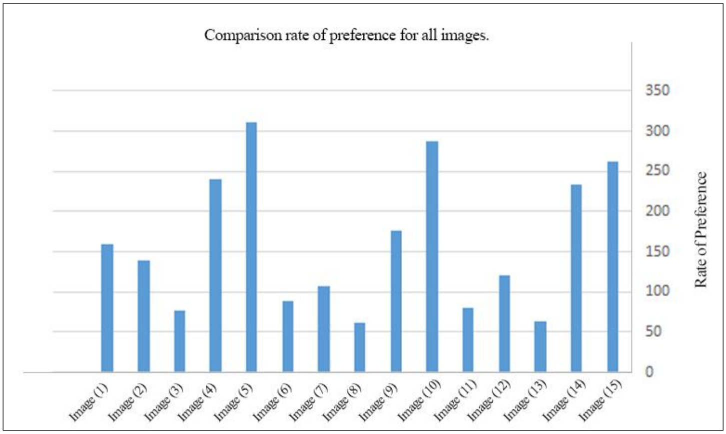

Fig. 19 – Comparison rate of preference for all images.

Fig. 20 illustrates that form (1) designed inspired by Egyptian Pyramids have better recalled resident's implicit memory to protect environment. This form was probably implying some natural elements such as mountain. Some respondents pointed out that simplicity of this form is associated with essence of nature.

Au contrary, form (2) had the least impact on reminding people feel their responsibility for environment. People mentioned that this form -designed inspired by George Pompidou Center- conveyed meaning of complication of modernism and technology.

Form (3) designed inspired by natural form was chosen as second preference.

The rates of preference for each color in different forms are almost the same. As a result, we obtained, at first impression, people are influenced by color.

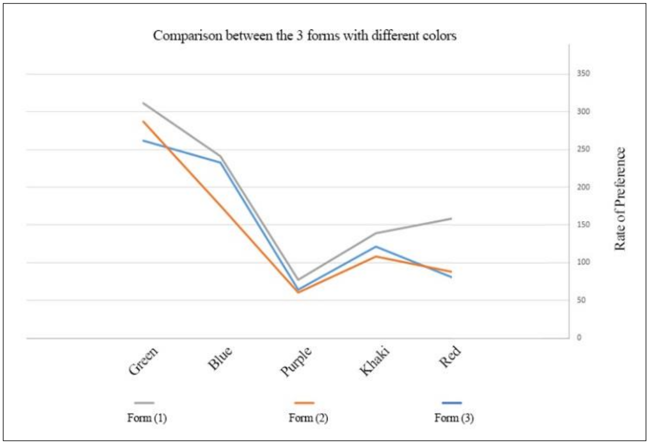

Fig. 20 – Comparison between the 3 forms with different colors.

4. Conclusion

In this study, we presented consequences of library and field research of how color and form of space evoke human implicit memory. A part of this memory is about symbiosis with nature. Through applying factors signifying nature in space design, humans repeat their initial relation to nature. This process leads to extract sense of responsibility to environment.

For this purpose, we designed a questionnaire to find the most meaningful color to all. We examined each color with various forms to investigate how in the effect of form in perception of color, in first glance. Consequently, we found that color is more influential than form.

Color green symbolizing nature impressed people more to protect environment. Color blue seen widely in nature placed in second level. Color khaki had less impact on recalling human implicit memory of co-responsibility than green and blue. Agreement of respondents with color red was less than khaki. Color purple was defined as the least influential color for our purpose. Why is probably that the color appears seldom in nature.

Surprisingly, the geometrical form designed inspired by Egyptian pyramids had more effect on people that curved form. The complicated form designed inspired George Pompidou center impressed respondents at least.

In this survey, we have focused on polychromatic colors, because monochromatic colors are rarely seen in nature. In traditional public spaces in my country, polychromatic colors have played a significant role when people respected environment, but today monochromatic colors are widely applied in modern public space design.

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Color and accessibility in underground wayfinding and signage design.

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1. Introduction

Color is one of the most influential assets in the language of visual design. It is often used to emphasize, differentiate or to connotate graphic messages in many different contexts from brand to interface design. Many of our interactions with the physical or digital environment surrounding us are mediated by chromatic information.
Although color blindness is not explicitly considered a physical impairment, it could be, therefore, a limitation in everyday life. In particular, many of the signage and way-finding system, such as traffic light, street signs, and so on are mainly based on the color codex. Moreover, in undergrounds maps, way-finding scheme, archigraphics, brand, and signage plans and artifacts make broad use of color language.
The paper presents and discusses this issues according to the Universal design/Design 4 all principles from a theoretical and an experimental point of view. Then, research maps and exemplifies some of the most relevant case studies in the history of underground signage design from the London Tube to the Porto project. In the end, the article proposes and debate the best practice and guideline of inclusive color signage design strategies.

2. Color blindness and the everyday life

Achromatopsia or *color blindness* [1] is a physical condition that affects a that affects almost an 8,5% of the world population with a prevalence of men [2, 3]. It consists of the total or partial inability to see colors that means that color blind people see not at all or a smaller range of different tints in the whole spectrum. Color blindness is not considered a proper disability; however, it can give some problem in everyday life. Many of the information that allow us to interact with the environment such as traffic lights, direction signs, error feedbacks, alert or emergency messages are often identified by the use of color [4].
One of the most trivial but significant examples is the traffic light in which color is the means to convey critical messages such us stop and go to guarantee safeness to every driver (see fig. 1). Although many attempts to solve the problem in a more inclusive way have already been taken, the example is paradigmatic to the difficulties faced in everyday life by color blind people.
A good practice of inclusive design is represented by *Uni-Sign the universal signal light suitable for color blind and everyone else* [5]. Developed by the South Korea designers Ji-Youn Kim, Soon-young Yang, and Hwan-Ju Jeon in 2009. The design studio joined both the combination of colors – of course – with shape language – triangle, circle, and rectangular – and positioning to give an efficient and unambiguous message (see fig. 2).

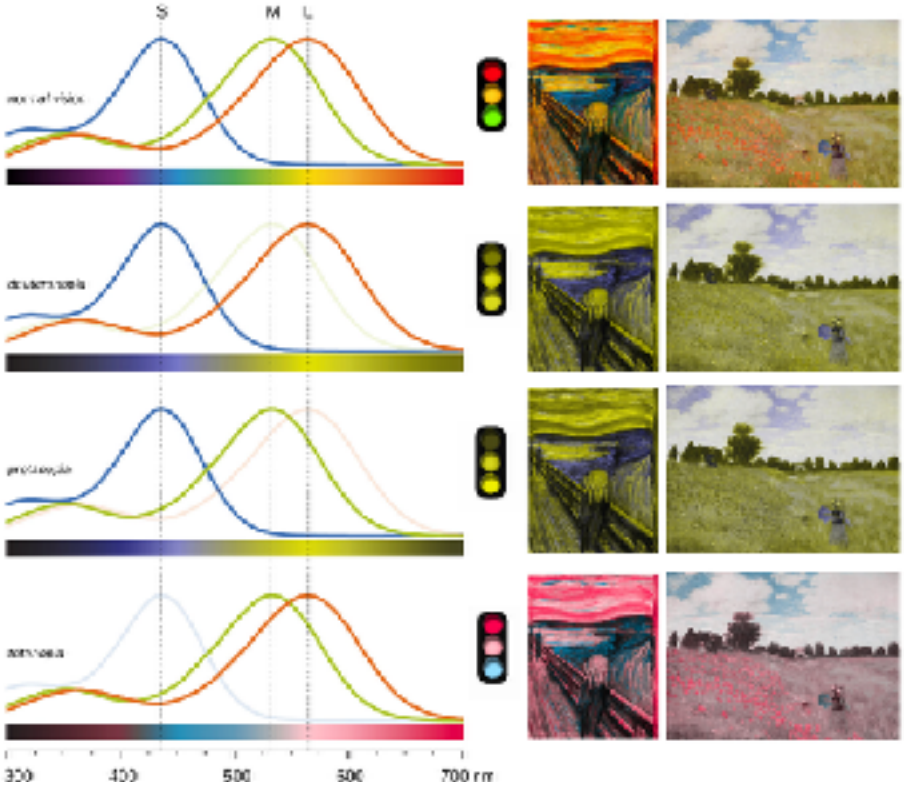

Fig. 1 - How people see colors: a) normal vision; b) deutoranopia; c) protanopia; d) trinopia (*Source:* http://mkweb.b-cgsc.ca)

Fig. 2 - *Uni-Sign the universal signal light suitable for color blind and every one else. (Source: http://www.yankodesign.com)*

3. Design for all: an inclusive and ethical design approach

In the last two decades, a new sensibility has raised among designers about ethical issues and inclusiveness. Given up the industrial idea of standardization that dominated Rationalism and the 20th century, the design community is now embracing the concept of diversity, weakness and different abilities.

Accessibility, inclusiveness, and enabling are the drivers of a new ethical approach to the main international movements such as Universal Design in the US [6, 7] and the Design for All in Europe [8, 9, 10] started in 1998.

A year before, the World Wide Web Consortium had already proposed the WAI (*Web Accessibility Initiative*) [11] a work in progress activity intended to guarantee the accessibility of the internet to people whit disability [12]. "The power of the Web is in its universality. Access by everyone regardless of disability is an essential aspect" is the declaration given by its inventor Tim Berners Lee, who strongly claim the access to information among the most important human rights [13].

On one hand, this program is deeply connected to a *user* – or better to say – a *human-centered* design approach [14]: as stated by IDEO who firstly adopted this definition "It's a process that starts with the people you're designing for and ends with new solutions that are tailor-made to suit their needs. Human-centered design is all about building a deep empathy with the people you're designing for; generating tons of ideas; building a bunch of prototypes; sharing what you've made with the people you're designing for, and eventually putting your innovative new solution out in the world." Putting *people first* is the mantra to keep in mind the users' needs and the contexts in which they will use or interact with our projects both physical and digital.

On the on the other hand to an ethical point of view on the role and the responsibility of designers [15, 16, 17, 18]. The issues of a design culture more concerned with social and long-lasting values have been expressed already since the late '50. The rise of consumerism and social inequalities, the works conditions of proletariats until the *liquid* Bauman's world, the cultural role of advertising are the topics of the First things first manifesto written by Ken Garlan in 1964 [19] and renewed in 2000 [20] and signed by about twenty colleagues. "There are pursuits more worthy of our problem-solving skills. Unprecedented environmental, social and cultural crises demand our attention. Many cultural interventions, social marketing campaigns, books, magazines, exhibitions, educational tools, television programs, films, charitable causes and other information design projects urgently require our expertise and help. We propose a reversal of priorities in favor of more useful, lasting and democratic forms of communication – a mind-shift away from product marketing and toward the exploration and production of a new kind of meaning. The scope of debate is shrinking; it must expand. Consumerism is running uncontested; it must be challenged by other perspectives expressed, in part, through the visual languages and resources of design."

In more recent times, empathy has become one of the more valuable ideas applied to the design approach that tries to be even more involved in the users' perspective. Understanding of the people you're designing for – not just observation or validation as in the traditional procedures – as a mindset of listening according to Indi Young: "Conventional product development focuses on the solution. Empathy is a mindset that focuses on people, helping you to understand their thinking patterns and perspectives." [21].

4. Way finding in the undergrounds

As mentioned before, although color blindness is not supposed to be a disability, it can cause difficulties in the everyday interactions, moreover in some specific context in which the chromatic language is the communication driver.
Way-finding and signage design applied to underground orientation systems is one of these contexts.
Frank Pick, executive director of London transport from 1913 to 1938, commissioned the signage system of the Tube that leads to the current project. He asked Edward Johnston of the realization of the typeface and a new brand, in 1916, and to Harry Beck the creation of a new map, according to some guidelines [22].
The process that led to the current map was long and implied the application of different design styles. The first London's public transport map was developed from the MDR, the Metropolitan District Railways. It was a geographical map, showing the lines of the subway shaped on the physical urban space. This solution which was increasingly blurred, along with the increase of the lines' and stops numbers of stops in the city center. Furthermore, the color was not used initially as a clue to identify better the lines (see fig. 3).

Fig. 3 - The London's Tube map in 1919. (Source: www.dailymail.co.uk)

In 1931, Harry Beck, an engineer, and a designer tried to solve the problem by taking inspiration from the shape of electrical circuits.
The new representation strategy was inspired by geometrical and quantitative laws as compressing areas containing fewer stops and dilating the center of the city solved the problem of excessive concentration of stops, decreasing the confusion.

Thanks also to the exclusive use of horizontal lines, vertical and diagonal at 45 degrees, of a chromatic code and an essential representation of the stops, the map was an immediate success (see fig. 4).
Most metropolitan maps worldwide, including the Milan's one, follow that of Beck.

Fig. 4 - The London's Tube map according to Beck's sketches and in a nowadays. (Source: www.standard.co.uk)

One of the most iconic, innovative and paradigmatic projects for a city underground is, in fact, the one designed by Boob Noorda with the architect Franco Albini since 1964 for the Metropolitana di Milano [23].
The Milan's underground is not one of the first realized in the world, nor in Italy, never the less it soon becomes of one of the most effective examples of way-finding system in orienting people in the passages' maze, interchange stations, and multiple gateways.
Color is the driver of the user's experience.
It names the different metro lines – Noorda initially designed the red and the green ones, and in the recent years the yellow, the *Lilla* (purple) and the under-construction blue have been added to complete the public transport system – and of the whole brand image.
The color, in Milan's underground, creates an immersive experience: it is not just the band that accompanies the signs and the carriages of the metro to be colored, but all the furnishing of the stations, from the handrail to the waste bins (see fig. 5).
This, combined with the use of innovative materials such as the floor with black stamps and the use of a new font redesigned starting from the Helvetica, both created especially for the red line, they mark the entrance in the contemporary era of the subways, and they were then reused in numerous signage projects of the tubes, from Vienna to Washington, from Brasilia to Madrid.
After the Noorda's project, many of the signage and way-finding projects have been developed according to its concept in which the color plays a strategic role, and for people with visual limitations in identify tints, it's a huge challenge. Although in a very complex system some other notation details – such as number or name – are used to differentiate the network and identifies the single line as in the Milan's itself or in the Tokyo project.

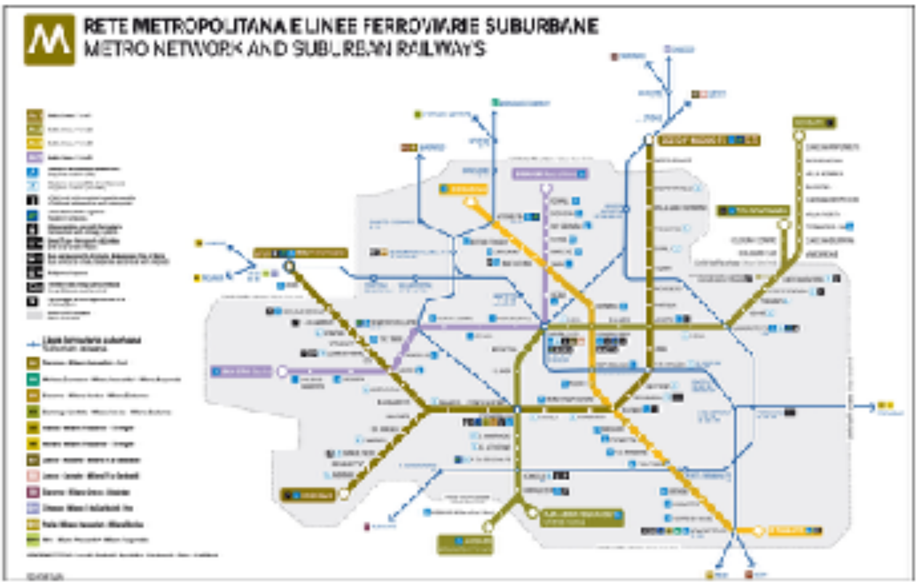

Fig. 5 - The Milan's underground map: a) normal vision; b) color blind vision, deuteranopic vision simulation. (Source: https://www.atm.it)

A solid compromise is represented by the Lisbon underground identity redesign. Opened in 1959, Lisbon underground added the second line only in the '90s due to the 1998 Expo [24]. Currently, it counts four metropolitan lines, each of which is associated with an evocative name: seagull, sunflower, caravel, east and according to the common practice to indicate the subway lines with the color that identifies them: blue, yellow, green and red (see fig 6).

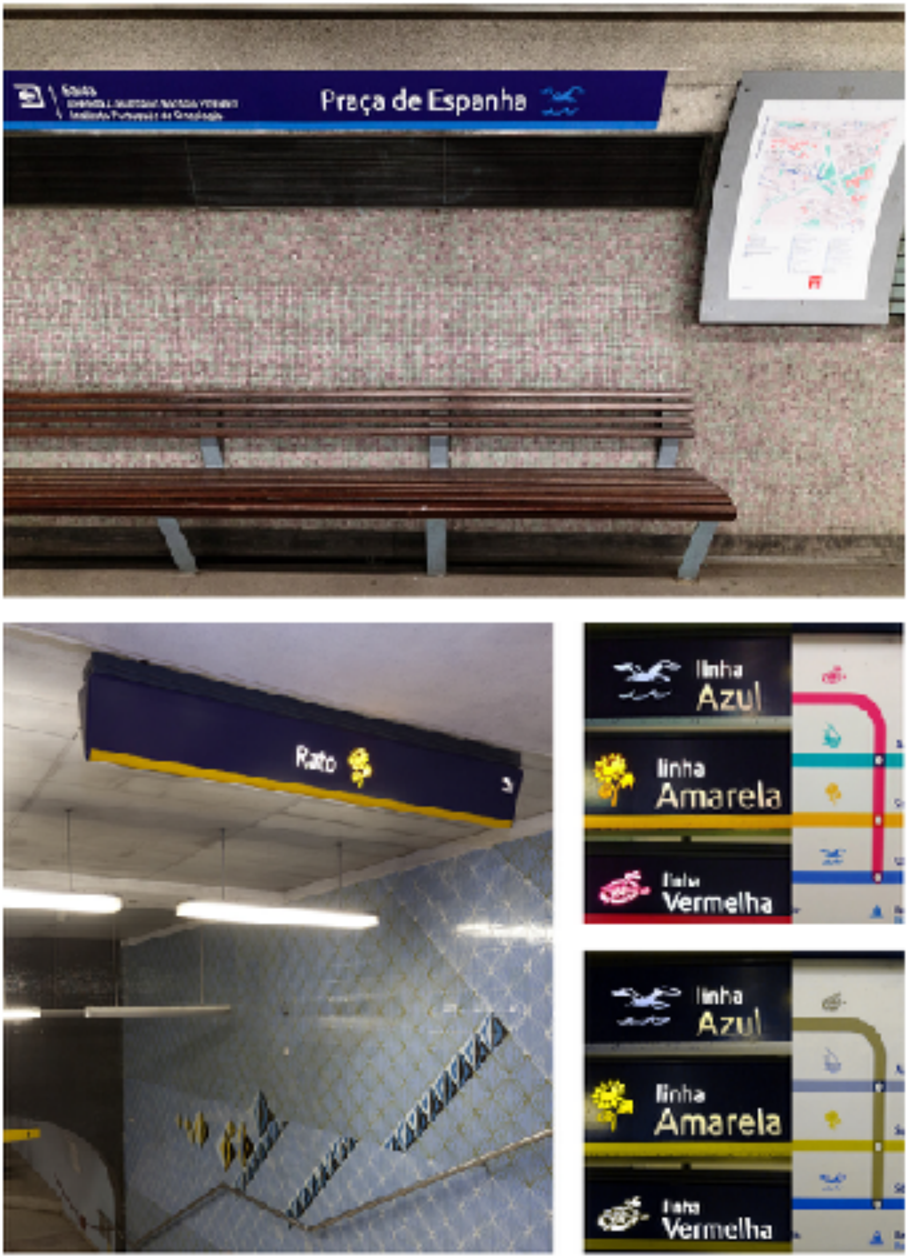

Fig. 6- The Lisbon's underground signage system (Source: www.metrolisboa.pt)

5. Universal Design: an experimental evaluation

In the light of these considerations, the research presented by the paper has mapped several way-finding solutions among the most known worldwide underground systems, i.e., Tokyo, Paris, Shangai, Berlin, etc.. In a second phase it has classified them, from the less to the more colors dependent and evaluated them – maps and signage plans – according to Universal Design principles, that means:

1. High contrast solutions;
2. Color is not used alone;
3. Sort and differentiate the elements in a describable way;
4. Ensure the visibility of the key elements;
5. Prefer monochromatic pallets;
6. Provide multimodal choices
7. Use patterns and textures;
8. Avoid specific color combinations;

Looking at the analysis results, we can deduce some recurrent phenomena.

The way-finding systems that use color as a secondary suggestion are much more uniform, according to the guidelines, compared to those in which the color covers a central role.

The quality of the latter seems to depend on precautions that allow the eventuality color evasion as a semantic clue and by the presence of combinations that can guarantee a sufficiently strong contrast between the elements. As regards the signage systems instead of the second type investigated, quality it seems always to be fairly uniform and good, because the color does not create a real obstacle to comprehension and orientation. A phenomenon particularly interesting is the fact that none of the analyzed signal systems seem to use plots and textures in environmental way-finding. Looking at the last column, finally (see fig.7a), we can note how at the level of accessibility for users the city with the worst signage system is color-blind of the subway would seem to be Milan, while they would seem to boast of a position of advantage the metropolitan areas of London and Lisbon.

Further more: in figure 7 a) each selected system is evaluated according to a Likert scale from 1 to 5, based on how much it is virtuous (5) or not completely followed (1) the UD guidelines. In figure 7 b) the radar charts show the accessibility level for the color-blind users offered by the subways

Finally, color blind subjects have been involved in an experimental activity to directly test the effectiveness and efficacy of the signage solutions adopted in the underground visual communication systems.

As well as declared both by Nielsen [22] and Krug [23] in their quick & dirty user test task based methods, composed of six subjects (Italian men living in Lombardy region) were involved in the study 21-54 years old, residents. The study purpose is to check which map was the most understandable.

The test was divided into three phases. In the first, color-blind users were asked to follow a path on four of the previously selected color maps: Milan, Lisbon, London in color, and the textured London one. The purpose is to verify whether the use of symbols r textures could solve the problems caused by color. In the second they were asked to order all eight maps dealt with in a personal order of legibility and comprehensibility. In the last phase was requested via a short questionnaire with

questions with an explicit or implicit answer to declare their familiarity with the viewed maps, to indicate any limits or merits and to provide their opinion about what they would like to find in a public signal system (see fig.7c). The first two phases were also proposed to an equivalent experimental sample of *normal* users.
All the tests were carried out in the presence of the researcher.

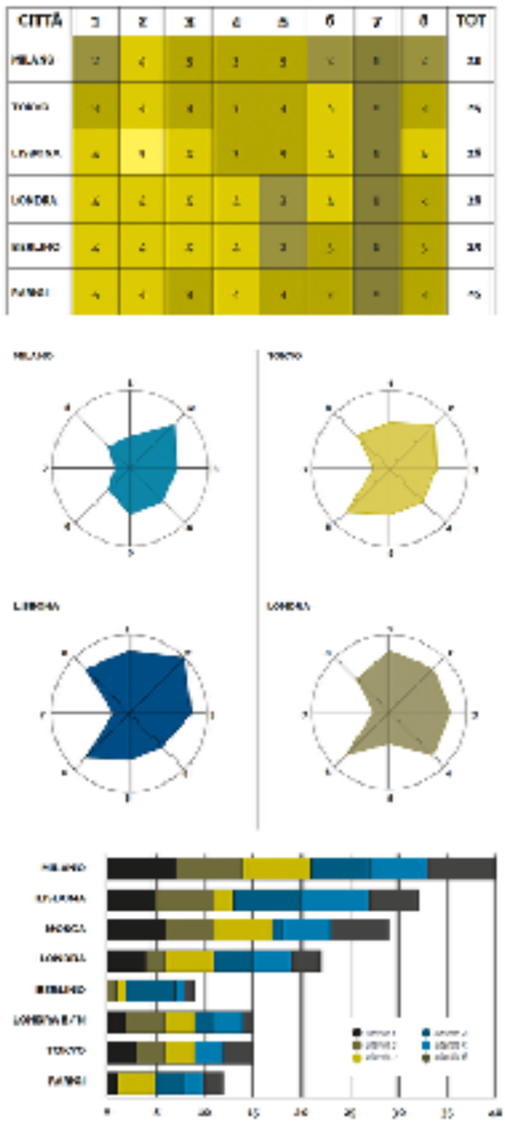

Fig. 7- Experimental results: a) expert evaluation; b) UD Guidelines evaluation; c) user test results

6. A possible best practice

A good example of ham to apply the Universal Design guidelines and, at the same time, integrate some meaningful elements to understand colors language has been proposed by Miguel Neiva. The project Color ADD - Color Identification System presented i Italy at the X Italian Information Architecture Summit is a universal solution to simplify the life of color blinds.
The system consists of a series of elementary geometric figures that can be combined with each other – as are the colors – which allows you to map and translate the chromatic message into a symbolic one. The applications are almost infinite and crucial: the signs and the subway plans, on the site a possible application is proposed to the Porto Metro currently being built [27].
The system allows using different modes of communication [28] within the visual system by encoding a grammar significant and modular, such as an alphabet.
As a natural language Color ADD can be combined and composed to produce new chromatic meanings and to construct coherent and comprehensible communication ecosystems [29] both for the ordinary users and for color-blinds.

Fig. 8- Public transport in Porto according to Color ADD System (Source: http://www.coloradd.net/transports.asp)

7. Conclusions

However some experimental tests have been carried out, the validation of these evaluation hypotheses need to be assessed in the real world to validate whit statistical data the analytical and theoretical assumptions.
The literature concerning this specific the topic is relatively recent and scarce; therefore it is necessary to enunciate some starting principles and defining the general framework within which the research has been developed and need to be improved.
Further future research development could be the involvement of a wider experimental sample, testing different subject, both male and female – including for example individuals affected by *tritanopia* (blindness in shades of blue and yellow) or taking into consideration of users with different geographic origin and several previous experiences in the field of public transport.

Nonetheless, the study opens new perspectives on the design activities that in vol public investment and user services

Acknowledges

The author would like to thank Chiara Castelli for the iconographic research, the testing activities and mention her final degree dissertation "Daltonismo e accessibilità. Orientarsi nelle metropolitane"

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8. COLOUR AND CULTURE

Affective Reconstructions: Poetics of Light and Colour Design in Contemporary Theatre in Tehran

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1. Introduction

Dynamics of light and colour design create unique aesthetic, affective, cultural, and communicative identity in any real, surreal, or virtual spaces. The current paper is an attempt to discursively investigate and to visualise the dynamism of light and colour design in the contemporary theatrical practices in Tehran, Iran. Theatre is a mediation space ‘in between’ the imaginative and the real world. Theatre, opera, and stage performances unifies various arts practices in dimmed lightening architectural spaces. Contemporary theatre is an inter-medial world of architecture, sculpture, literature, scene design, performance, acting, music, art of dialogue/monologue, mode, makeup and costume design, projection, video-mapping, 3D sculptures, media design, and compositions offered by emerging digital and intelligent media, inter alia. The dynamics of light and colour remain among the central forces in navigating the audience gaze, in leading the storytelling, and in reconstructing affect, e.g. emotion, desire, attention, aesthetics, pleasure, mood, etc.
Some believe that light and colour as individual elements do not have theatrical meanings, rather, at a micro level, the context and situations of scene create mediation effects for light and colour [8]. The usage of dynamics of light and colour in theatrical performance, at a macro level, depends on various factors, including the theatrical and performance culture, directing decisions, the nature of story/performance, aesthetic tastes, theatrical visual literacy, media- and visual-culture, genre preferences, colour world, colour code, colour identity, technological and creative feasibility for scene and light designers, inter alia, in a given culture. These factors can influence the colour spectrum and light design composition (e.g. natural lighting, realistic effects, abstract, abstruse, fanciful, imaginative, dramatic colour blend and lighting, etc.).
Theatre is a vulnerable art practice in Iran. During the past few years, nonetheless, it gained noticeable attention from the public and opened creative possibilities for colour and light design expressions. In the current paper, the dynamics of light and colour design in theatre are investigated in relation to *media culture* and *colour code* in Tehran. The method of analysis is discursive in nature and the case studies demonstrate the colour palette of selected theatrical light and stage/costume design. The attempt is made to avoid any universalisation and generalisation of the practices. The conceptual framework of the paper is based on the nexus of mediation, affective and the cultural.
Mediation is “a non-linear” series of “movement of events,” “bodies,” or “conjuncture” in transformations [1]. Forms of mediation, as the process of becoming cultural, can be specified theoretically in the context of medial spheres. Medial spheres are epochs of media practices comprising, the cultural, communicational and temporal dimensions [2]. These spheres can be broadly identified as *presentational*,

representational, *mechanical*, *electronical*, *intelligent,* and *biological* medial spheres [2]. Analysing the affective reverberations of colours in a cultural context requires a closer investigation into various forms of mediation and medial spheres. For instance, the theatrical practices, as the legacy of the (re)presentational medial sphere, are entering into a new dynamism in the contemporary intelligent medial sphere, marked by new forms of mediations, e.g. hyper-aesthetics, interface design, networked/information concepts, algorithm, glocalisation, digital colouration, discrete aesthetics and formations, versatile colour expressions, etc., which are reconstructed culturally.

Affect is considered as the "energy of mediation," which "operates on multiples planes" and "apparatuses, with varied effects" [1]. Colour is, respectively, a significant affective element. Despite the common belief which defines affect as "a single apparatus, or a single type of effect," which is non-representational, unmediated, instinctual, non-conscious, non-intentional, and non-cognitive, affect is a "complex set of mediations/effects," comprised of three dimensions of *virtual*, *actual* (materiality of mediation) and *constructive cultural* existence ("discursive formations") [1]. The first two aspects are the "expressive strata," while the third dimension is "the multiplicity of regimes, logics, or organizations of intensities or passions (*affectus*)," which determine the "affective tonalities and modalities of existence, behavior, and experience" [1]. The third aspect "mobilize and organize affect as the habitual, the lived, and the imagined" within "larger articulations" of discursive formations or apparatuses of the cultural" [1].

The socio-cultural context in the current paper is considered Tehran. The Iranian culture from antiquity is celebrating light in various form and formless possibilities. From Zoroastrianism to the philosophy of Illuminationism (Hekmate Nour), in every poetic expressions, ritual and artistic practices, the light is considered as the most vital and sacred element. Besides that, the rich cultural ethnicity in Iran, throughout the history, introduced a wide range of colour harmony and aesthetics into architecture, interior design, artefacts, carpets, textile, and instrumentations. Tehran, a gigantic metropolis, with various cultural ethnicity, suffer from disparity of colour harmony in urban spaces and public spheres. Prior to examine the spectrum of light and colour usage in the contemporary theatre, based on the mediation, affective and cultural dynamics, it is significant to have a bird's eye view on the colour code in Tehran. The correlation between the affective dynamics of urban colour code and lighting space design in contemporary theatre is not linear, rather a complex interrelation in building the colour identity.

2. Digital Colour Measurement: Methodological Framework

The methodological approach, in the current paper, is discursive-analytical in nature. The aim is to discursively analyse and visualise the colour code and light design in the contemporary theatre practices in Tehran. The context of the colour harmony analysis and light deign aesthetics are the cultural factors, including colour aura in Tehran from public to private spheres. The digital colour palettes (5 major colour hex) are measured by Adobe Capture (Adobe Color CC) app. The major data collected are digital photographs by professional and semi-professional cameras. The following figure demonstrate the scaling of the colour palette.

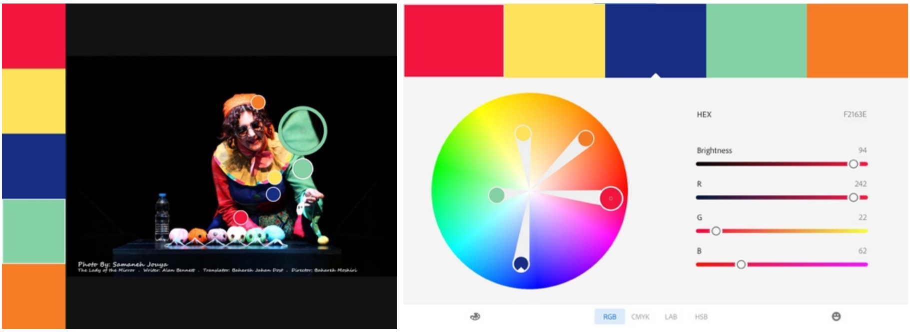

Fig. 1 – Colour schemes generated by Adobe Color CC Application. Image: *A Lady of Letters* (2017) – Writer: Alan Bennett, Translator: Bahareh Jahan Dost, Director: Bahare Moshiri, Photo by Samaneh Joya.

Another measurement tool is the online website of clarifai.com, which measure the colour palette in terms of percentage. The colour naming in this website may not necessary match the actual colour terminology used in Iranian culture. The both digital measurement tool may not appear efficient in measuring the natural setting mineral colours, for instance, cyan in traditional architecture of mosques. In terms of industrial and structural colours in interior setting, the digital capture of colour is relatively precise.

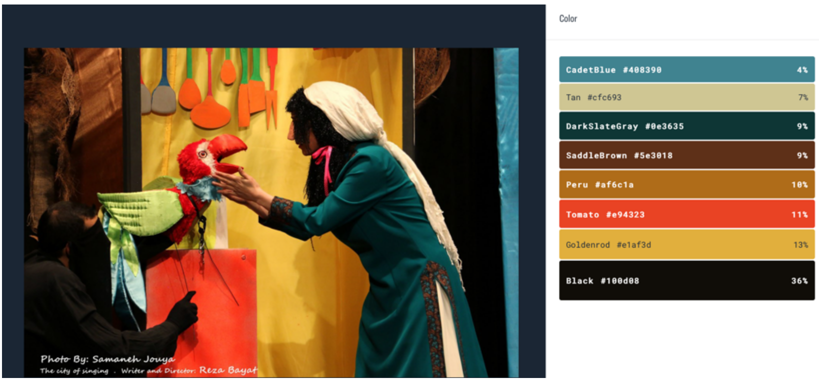

Fig. 2 – Colour schemes generated by clarifai.com/color. Image: The City of Singing (2018) – Writer & Director: Reza Bayat, Photo by Samaneh Joya.

Furthermore, in order to generate monochromatic colour scheme, including the tints (white mixture - increased lightness), shades (black mixture -decreased lightness) and tone (mixture of black and white), analogous colours, complementary colours, triadic colours, the online portal of color-hex.com is used (these features are also accessible in Adobe Color CC). To reflect on the mediality of the small data via photography, there is a constraint of representing the wide range of practices. In future studies, the big data analysis may help to achieve a representative colour map of practices. The small data gathered by cameras, however, can be practical in capturing the vibrant case studies.

3. Tehran Colour Codes: From Public to Private Spheres

Cities around the globe may have certain colour code identities, depending on the public spaces (urban colour design), market structure (brand and advertising intensity and diversity), transport, architecture (façade and interior colour codes), and social-cultural groups (dress codes and make-up), among others. The colour and light design in every stratum may be influenced by various factors and it is in course of proliferated transformation due to globalisation and digitalisation. The colour design in artistic spheres, such as contemporary theatre, may be widely influenced by the spirit of the time (Zeitgeist), and glocal aesthetic in reconstructing the affective modes.
Tehran as a capital is multicultural city and has complex social class structures [5]. The colour codes across contemporary Tehran are in flux of drastic discrepancy depending on the structures of spaces (the landscape view), municipal (festivals) decorative policy (22 municipal districts), old and new architectural design, renovations, organizational and institutional design policies, and billboard advertising, inter alia. The air and visual pollution in Tehran have created grey tonalities to the landscape view of the city.

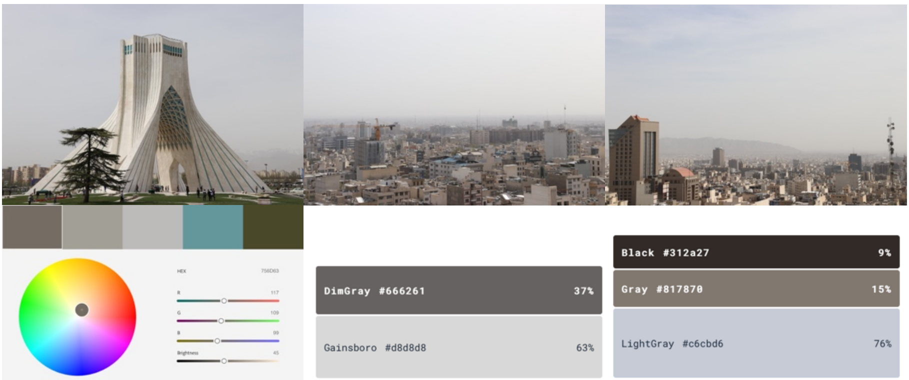

Fig. 3 – Central Tehran – District 9-6, 2018. Photos by Maryam Bolouri.

The street view in daylight may range from traditional colour harmony in Mosques architecture (cyan, blue, green and gold natural colour combination in Persian tile art), the typical architectural façade from stones, bricks and concrete (brown, black, white, and grey), to streets/highways and cars industrial colours (black, grey, white, and silver).
The traditional colour harmony in architecture is usually the extension of the colours of the nature, cyan (the sky), earth brown (the mountains), and gold (the rays of the sun). There are other cultural symbolisms and values to any of these colours historically. The new sets of industrial colours are usually implemented without specific harmony and may create a colour shock across the city. The light design during night are usually the industrial LED or Neon light sources.

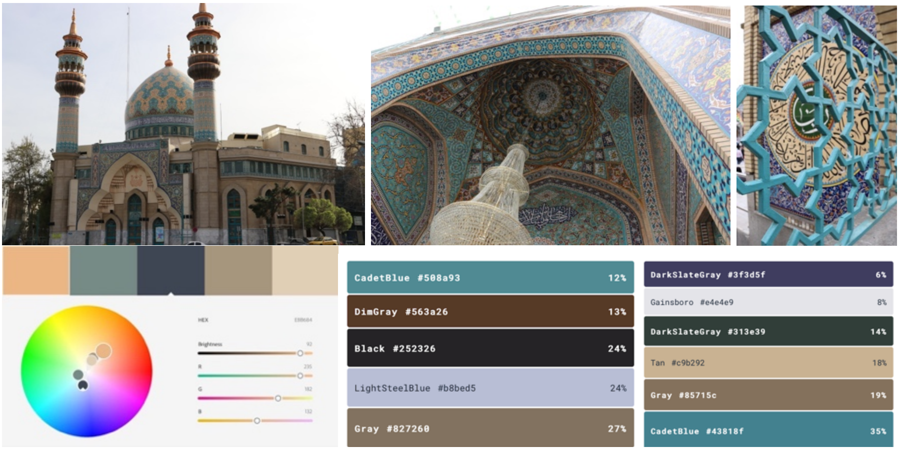

Fig. 4 – Traditional colour harmony in mosques architecture, Day Light – Tehran, Palestine Sq. (left) and Tajrish (right), 2018. Photos by Maryam Bolouri.

According to a study conducted in Tehran, the major colour of cars sold during 2004-2008 were silver (28%), white (21%) and grey (13%), followed by dark grey (6%), black (5%), and beige (5%) [7]. A psychological analysis demonstrated that despite the fact that most people associated achromatic colours, such as white, grey, silver and black with depression, inactivity and boredom, these colours are among the top sellers in Tehran [7]. The industrial colours are visible in wall painting decorated by municipal districts, educational buildings (especially primary education and kindergartens are using extreme colour expression in exterior and interior design), decorative flags and advertisement billboards.

Fig. 5 – Central Tehran – District 9-6, 2018. Photos by Maryam Bolouri.

During the night, Tehran has a new face, due to the various light design and projections across the city, especially during the festivals. The major light colour is green (having religious (Islam), spiritual and nature-link connotations). Besides that, neon lights (both decorative and advertisement) give unique glamour to the city. The urban light projection (video) mapping or light sculpting is not fully introduced in Tehran. The lightening of the buildings is remained static and polychromatic colour combinations.

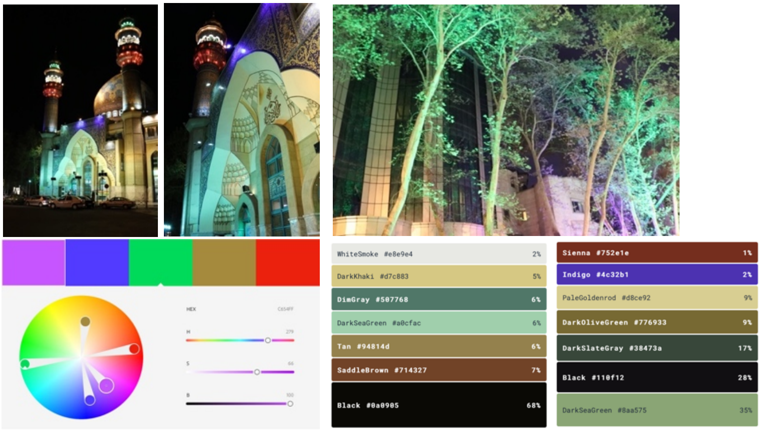

Fig. 6 – Light projection, night – Tehran, Palestine Sq. (left), Valiasr Ave. (right), 2018. Photos by Maryam Bolouri.

The colour worlds and colour codes in private spheres varies considerably among socio-cultural classes in Tehran. It is not possible to capture the diversity of the colour spectrum within the limitation of the current paper. It can be highlighted that the decorative interior design, carpet and furniture enjoy traditional as well as modern colour language. The colour and light in interior design inside semi-private and public spaces, e.g. institutions, governmental offices, etc., highly depends on the origin/time of construction and the type of functionalities.

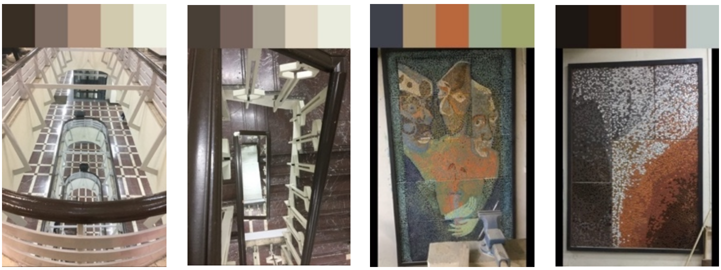

Fig. 7 – Tehran Architecture and Art University – Interior and Art Works, 2017. Photos by Maryam Bolouri.

The examples mentioned in this section can be considered as a small window to the colour atmosphere confronted many citizens in Tehran. The ultimate objective in this colour worlds context is to visualise the types of colour spectrum in contemporary theatrical practices.

4. Dynamics of Colour and Light in Contemporary Theatre in Tehran

The contemporary theatre is considered as an artistic universe of a wide range of art forms and media practices, comprising sculpture, stage design, architecture, painting, music, singing, costume, textile, mode, light design, performance, immersion, installation, video mapping, programming, augmented reality, and mobile apps, inter alia. The wearables, smart textile, and innovative light technologies have introduced new opportunities to transform affective reconstructions of moods and emotions, the dynamics of storytelling, motions of scenes and versatile design element [8]. The usage of dynamics of colour and light in contemporary theatre, however, is influenced

by many factors, including, a) *economic factors*, e.g. production costs, time of implementations, properties of theatre halls, etc., b) *visual culture*, e.g. viewing habits, colour and light exposure, colour aesthetic, colour significance, colour literacy, colour codes, etc., c) *cultural values*, e.g. colour value, colour norms, political and religious values attached to colours, etc. d) *spirit of the age* (Zeitgeist), e.g. collective aesthetics, intuitive patterns of expressions, etc..
The history of theatrical practices in Iran enjoys long-standing and diverse traditions. Dramatic literature and poetry illustrated later with Persian miniature were parts of cultural history in Iran. The practices span from Baqqal-Bazi, puppets, dramatic epics of Shahname, folk, elegy, religious epics/plays, passion play (Tazieh-Khani), and modern theatre (influenced by European theatre), to contemporary theatre [9]. In traditional and religious plays, the performances were in any public spaces, without stage or light design. Therefore, the colour is mainly used in costumes, as a technique for personification of characters, representing their religious views, social classes, and their cultural values. For instance, in Baqqal-Bazi, some figures generally had certain dress codes and make-up, i.e. clever servant in blackface and red costume. In religious plays, passion plays (Tazieh-Khani) – which narrates the story of the third Shia Imam – the colour codes of costume are very significant. The (dark) green is the symbol of innocence, truth, representing Shia Islam and its followers, and red is the symbol of arrogance, injustice and death. The modern theatre, a new form of mediality happening in certain space/time, introduced the theatrical practices of space and stage design in Iran.

Fig. 8 – City Theatre Tehran. Photos by Maryam Bolouri.

In contemporary theatre, arguing for general or recurrent patterns of colour symbolism and colour code is a vain attempt. It seems that, the colour and light design on stage, in contemporary theatre practices, are used either as (re-)constructive elements for the decorative objects on set, designing emotions and moods, expanding the imaginations, narrating and storytelling (rather than characterisation and personification) or/and as the expressive artistic signature of the play. The types of facilities available in theatre halls may vary considerably. Some prominent buildings are historical, which are reconstructed before Islamic Revolution, i.e. Roudaki Hall (1967, initially built as an Opera House), City Theatre (1972), and some are newly reconstructed complex. The less known directors may perform in smaller theatre halls or artists houses. Dynamics of contemporary light design, in general, is adding new expressive language for many practitioners. Specially as the new trends of musical theatre and modern opera genre are uprising in Tehran and other cities, the complex light design program and the use of video installations/projections are adding new visual flavours. In the following some examples of light designs are visualised and discussed.

4.1. Case Studies: Light Design on Stage

There many facets of colour and light design in theatre. Colour can perform as catalyst, exaggeration tool, alienation effect, mood building, emotion arousal (fear, love, etc.). The formal characteristic of colour which can be reproduced in every performance, disregard of acting, is based on familiarity effect [8]. The colour and light composition introduce new design language and create cultural narrative style.
Due to the cost and time of production for young artists in Tehran, the light compositions are usually limited to major stage light sources, blue and red. Since the green light has a religious association, it is not frequently used in contemporary dramas. The use of yellow light is also limited. Although, traditionally, yellow is considered as an important element in carpet and kilim design [11], the yellow light is rarely implemented on stage, denoting death and decline (fig. 10). The gold, in contrast is used to show the elegance and pride.

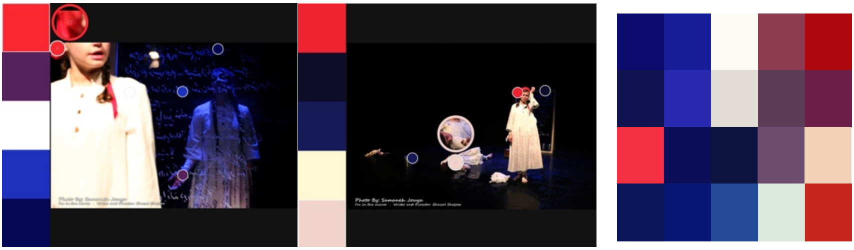

Fig. 9 – *The Me in the Mirror* (2017) – Writer/Director: Ghazal Shojaee, Photo by Samaneh Joya.

The dark blue light is used to create an imaginary, dream-like, unconscious, and mysterious space. It can also create the romantic mood and sacred spaces (fig. 12). The use of red in accessories or custom reverberate the wide range of emotions, from fear, passion, to feminine element. In the contemporary culture, with reference to eight years of Iran-Iraq war, red may also signify the martyrdom, protection, and justice. The red in some cases symbolise the centre and the uniting element [6].

Fig. 10 – *Strangely Enough* (2017) – Writer: Shahab Mehraban & Sepehr Zamani, Director: Ara Fayya, Photo by Samaneh Joya.

Fig. 11 – *Conversations of Dead* (2017) – Writer: Mohammad Zarei, Director: Milad Shajareh, Photo by Samaneh Joya.

The implementation of colour may intensify by using the window glass effects. This technique can produce oriental or occidental colour spectrum (fig. 12 & 13). The complex colour structure can reverberate the emotions and tensions of the story, which integrate the affective intelligence of the audience.

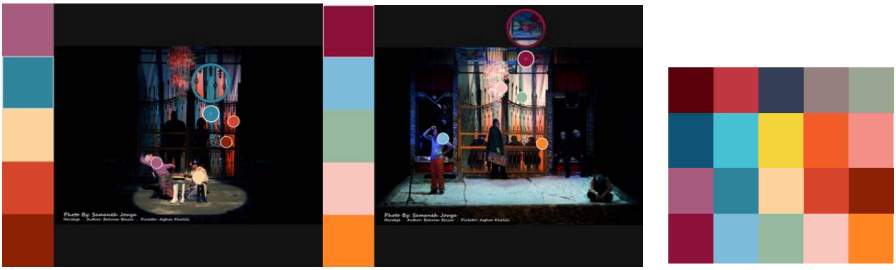

Fig. 12 – *Heritage* (2016) – Writer: Bahram Beizai, Director: Asghar Khalili, Photo by Samaneh Joya.

Some artists try to reconstruct the traditional colour harmony in new expressive ways. There is a nostalgic tendency in reviving traditional colours, which denote some cultural meaning. This trend can be seen in the modern design of art café houses and restaurant in central Tehran. Specially the intellectual artists are in search of the traditional elements and colour patterns, in order to re-introduce them in their design.

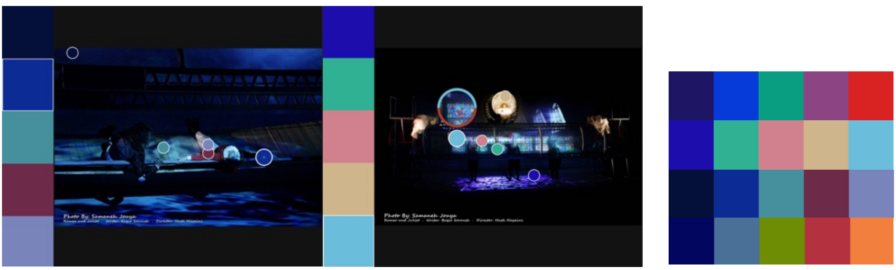

Fig. 13 – *Romeo & Juliet* (2017) – Writer: Baqir Soroush, Director: Hasti Hosseini, Photo by Samaneh Joya.

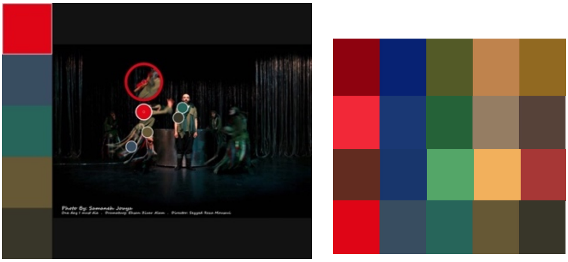

Fig. 14 – *One Day I Must Die* (2017) – Dramaturge: Ehsan Zivar Alam, Director: Seyed Reza Mousavi, Photo by Samaneh Joya.

In contrast to adult theatre, in which the dynamics of lights plays significant roles, the children's musical theatre, which is expanding in Tehran and other major cities, is based on the personification of character through colour. The range of colours used in costume, make-up and stage design span across the colour wheel (fig. 2 & 14).

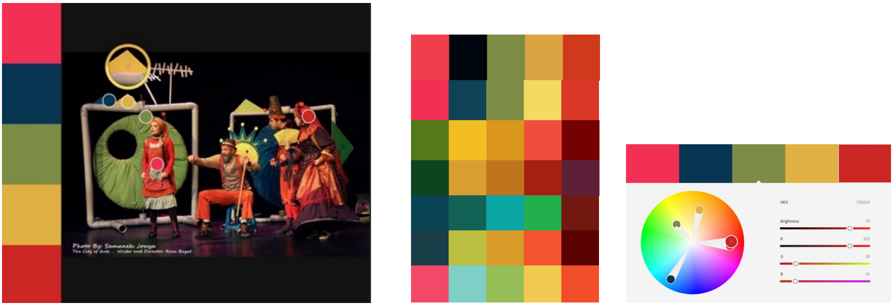

Fig. 15 – *The City of Ants* (2015) – Writer/Director: Reza Bayat, Photo by Samaneh Joya.

Similar to the expressive use of colours in urban spaces for children, the theatrical performances are colourful worlds. Inevitably, the exposure of post millennials (igeneration) to digital screen and colourful story world is higher than their previous generations.

5. Conclusion

Analysing the dynamics of colour and light design in contemporary theatre in the capital of Iran, Tehran, is complex and require cultural and contextual investigations. The contemporary theatre practices engage more citizens as the genres of productions are combining the musical and theatrical forms. Children theatre is uprising drastically attracting young families. Unlike traditional plays – with certain colour symbolism, contemporary theatre, as a medial space, can provide sphere for the extension of imagination and emotions beyond the real worlds. The light design and colour spectrum exhibited in this particular mediality, can enrich the sensational and affective experience of the audience. Tehran, as an ever-expanding metropolitan city, suffer from colour disharmony at many levels. The greyish pollution has created a visual filter across the city. The colour inconsistency across the city landscape and public spaces on the one hand, and the rich colour harmony and aesthetics in Iranian art traditions, existed in private space, i.e. carpets, furniture, miniature design, etc., on the other hand, has created poles of colour worlds. Perhaps, the contemporary theatre, can provide an “in between” medial world, where a new colourful visual realm and an imaginary world of signification can be (re)constructed. The new light technologies and various forms of new media projection-based practices, e.g. video mapping, video installations, etc., provide new visual expressive tools and an open field for stage and light designers. The versatility of changes in light compositions, and the influence of “moving colours” in contemporary theatre are noticeable and call for further investigations.

Acknowledgement

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A synesthetic interpretation of space through the colour of music

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1. Introduction

In the period of the historical avant-garde movements of the 20th century, research into synesthesia in the arts was a recurring phenomenon in the declarations of intent characterizing the various fields of knowledge. Certain well-known figures are remembered not only for their considerable interest in the theoretical argument, but also as a result of their planned and realized concrete experiences. Fusions were proposed on the conceptual and perceptive levels with the idea of totally involving the subjects experiencing these expressive moments.

Analogies between vision and hearing were analyzed and applied by various musicians, such as Skrijabin, Wyschnegradsky and others, in the wake of late Romantic experimentation. Simultaneous manifestations of colour and sound interlaced the pictorial and musical languages with transversal relations, both fruit and source of avant-garde artistic research (Kandinsky and abstract art).

The “transcription” of single notes or the perception of a musical piece as definite colours or atmospheres produced by colour sensations were converted into schemes of correspondences, symphonic poems, musical instruments, spatial concepts. Graphic signs for musical and figurative communication drew close to the definition of spaces, following compositional and conceptual perceptive approaches traceable to a common root.

A comparison between the sound/colour attributions with the contemporary theories on colour are a main field. Where the concrete practice of sounds and music also enters into the definition of a space created by the colour of music, such situations could be analyzed through an “architectural” representation in order to grasp their deeper meaning.

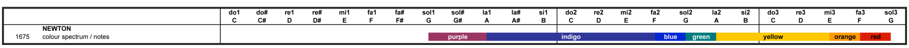
2. Perceiving together

This paper concerns the sphere of synesthesia, the putting together of different arts and the various perceptions of them, and the connections between their specific characteristics.

The concept of synesthesia is encountered in literature (a particular type of metaphor by which two words referring to different sensory spheres are closely related) and in medicine (when usually an auditory or visual sensation arises in concomitance with a perception of a different sensory nature) where it is specified that a visual image can arise following a usually acoustic stimulus (so-called colour hearing). This latter medical observation interests us particularly since scientists and scholars from the 17th century have carried out research on a coloured vision of music. Synesthesia therefore, in its etymological sense – συν 'together' + αιστανομαι 'to feel, perceive' – is at the basis of studies and experimentation whose aim is to increase man’s receptiveness in front of a work and stimulate the possibility of “perceiving together” a certain form of expression, whether it is art or science, in more than one sensory form [1].

3. Space and time

Once you apply a visual element relating to music, you introduce a spatial dimension beside the temporal one that is typically attributed to this art. The idea of somehow representing the world of sounds is a way of “capturing” the kinetic action of making music and representing it by means of a universally comprehensible language. The musical score has its own spatial dimension, legible to those who know the rules of notation and harmony of that period, that is, those experienced in the field, and perhaps not even to all the latter, particularly in musical notation from the second half of last century onwards when graphics were reinvented together with new, post tonal system musical conceptions.
Space is an attribute typical of architecture because it is space that architecture shapes and composes. The connection between constructed space and the dimension of time can be translated at various levels into reflections that range from the more philosophical, involving man and activity on a territorial scale up to the using of everyday objects, to more purely technical aspects such as the durability of materials. It would be necessary to wait until the early 20th century to have the first theorization of the use of colour in architecture by Theo van Doesburg and thus the opening of the way toward the study of colour perception both at an urban level and at the level of interiors, with reciprocal influences involving painters and other exponents of the avant-garde movements (in particular abstract artists who used colour as a central compositional element in their works).
In the 20th century the question of sonic space began to be addressed in a more structured way. New dodecaphonic, later serial music, developed by Schoenberg, worked just like architecture in that it “constructed” space with the creative gesture of the composer, whereas in the tonal system there already existed a structure within which the composing musician was obliged to operate. The use of words typical of the architectural world became increasingly frequent (Boulez); for some space derived from time in an organic and interlaced way (Stockhausen), while for others space was "outside of time" (Xenakis). An analogy can be made between the tectonic and plastic properties of architecture and structural and expressive characteristics, in other words, between the geometric and physical characeristics of space. On the musical front the first grouping (tectonic / structure / geometry) is the logic at the basis of the so-called formalism of a constructed space, while the second grouping (plasticity / expression / physicalness) refers to a more intuitive genre, in which the area of experience is the frame of reference [2]. Of the two, the latter is the one we are referring to here, since it embraces the idea of being able to learn to acquire new and original spatial qualities starting from an auditory experience.



Tab. 1 - Chart of corrispondence colours / intervals for Newton (processed by the author).

4. Objectifying the impalpable

At the end of the 1950s Le Corbusier created a new collection of colours for the Swiss company Salubra; he compared the juxtaposition of the various colours to the keys of a piano, such that they formed a "keyboard of colours". He thus related the particular conditions of spatial perception and music, possibly seeking, thanks to the fourth dimension, that "magnification of space" which he talks about in his *L'Espace Indicible* (1948), to find "the moment of limitless escape evoked by an exceptionally just consonance of the plastic means employed" [3] [4]. Can we consider music, like shapes and colours, a plastic entity? Some people have attempted to make this synthesis and have certainly influenced the emergence of a particular interest in the planning of colour, starting – as often happens – from fleeting and less obvious situations, from experimentation bordering on the extravagant and resulting from fields of application unrelated to architecture.

Newton's late 17th-century discovery that white light was the sum of all colours, and that these colours were distinguished by passing white light through a prism, provoked a series of considerations. Newton himself linked the rainbow to the sound "spaces" (intervals) of the diatonic major scale, even referring to the propagation of light and sound by waves (Tab. 1).

During the 18th and 19th century many scholars sought to discover a correspondence between colours and single notes to find a way to play an instrument which, besides emitting a melody, visualized the sound with colours. There were various reasons for an operation of this kind: to enable deaf people to see music, theoretical investigation, to understand the nature of colour in different ways (superimposition, combination, analogies …). These scholars were people of immense culture and erudition, interested in general in the new potential of the sciences and therefore ready to carry out research in all the various fields of knowledge.

The construction of such instruments was extremely complex and often failed to produce the results that were hoped for. The perception of sound compared to colour varies in its immediacy and the satisfaction of the listener was therefore relative. Moreover, when it was possible to use lamps instead of candles – which became increasingly powerful to create clear distinctions of colour – these instruments/devices frequently caught fire due to the amount of heat emitted.

There exists an abundant body of literature on the subject of colour-emitting musical instruments [5] [6] [7] [8] [9]. What interests us here is to draw attention to that desire to create special atmospheres, imbued with new sensations even with the aid of chromatic effects (Tab. 2). In the period of the historical avant-gardes the explicit request for a total work of art spurred composers belonging to the various artistic schools to adopt the use of colour in musical performances, colours modulated with painstaking care to create a space in which the spectator became immersed and was thus able to fully understand the artistic message [10] [11]. Instruments were in fact abandoned and recourse was made to extra-instrumental projections, useful in constructing what today we would call "immersive realities" [12].

Year	Author / instrument	do1 C	do# C#	re1 D	re# D#	mi1 E	fa1 F	fa# F#	sol1 G	sol# G#	la1 A	la# A#	si1 B
1723	**DIEZ**	red		yellow		green	various		blue	white	black		grey
1735	**CASTEL** ocular harpsichord	blue	b-g	green	g-y	yellow	y-o	orange	red	r-p	purple	p-i	indigo
1739	**MIZLER**	red		orange		yellow	green		blue		indigo		violet
1743	**KRUGER** ocular harpsichord	red		golden y		sulfur y	green		sky blue		purple		violet
1760	**EULER** *Letter 136*	purple		red		orange	yellow		green		blue		violet
1789	**LEFEBVRE**	blue		green		red	indigo		yellow		orange		violet
1845	**FIELD** *Chromatics*	blue		purple		red	orange		yellow		y-g		green
1862	**SUDRE** *Solresol* language	red		orange		yellow	green		blue		indigo		violet
1877	**BISHOP** colour organ	red	scarlet	orange	gold	yellow	y-g	green	aquamarine	blue	indigo	violet	v-r
1893	**RIMINGTON** colour organ (frequecies in millions of millions / sec)	395	433	466	500	533	566	600	633	666	700	733	757
1910	**SKRJABIN** clavier à lumières	red	violet	yellow	flesh	sky b	deep r	bright b	orange	lilac	green	rose	blue
1909	**CORRA e GINNA (Corradini brothers)** chromatic piano												
1916	**BARANOV-ROSSINE'** optophonic piano												
1918	**HALLOCK-GREENEWALT** colour organ *Sarabet*	**no specific correspondance**											
1928	**GIDONI** colour organ												
1932	**CASAVOLA** *Le atmosfere cromatiche della musica (Manifesto futurista)*	orange		yellow		green	blue		indigo		violet		red
1933	**LEONARDI** *L'unità della natura*	black		orange		red	green		blue		grey		
1934	**TENNERONI** *Un nuovo sistema di scrittura musicale*	black		orange		red	green		blue		grey		yellow

Tab. 2 - Chart of corrispondence colours / notes (processed by the author).

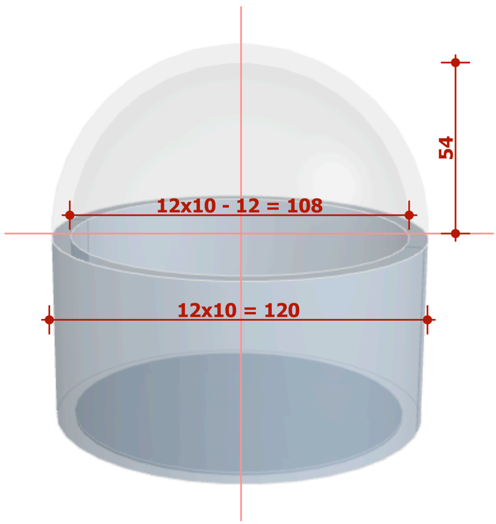
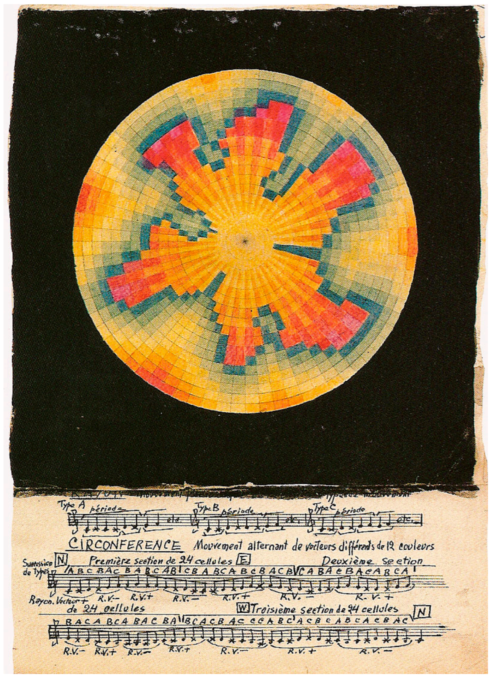


Fig. 1 – Three-dimensional reconstruction of the “Temple of light” by Ivan Wyschnegradsky (processed by the author).

Fig. 2 - Chromatic study by Ivan Wyschnegradsky with the indication of the construction of the grid that is repeated in the same way in all the chromatic studies. Devide the circle in 4 sectors. The horizontal and vertical deviding lines identify (clockwise) north, east, south and west. Each quarter of the circle is devided in 36 parts and so trace the relative radiuses. Devide the rasdius in 36 parts so to obtain the same number of concentric circumferences. The intersection the two polar grids forms (36x4x36) = 5184 tiles. The colours used are always 12.

Fig. 3 - Chromatic study by Ivan Wyschnegradsky.
Fig. 4 - Chromatic study by Ivan Wyschnegradsky.



5. The case of Wyschnegradsky

Ivan Wyschnegradsky (1893-1979) was an important exponent of the musical artistic avant-garde in Europe. A native of St Petersburg, from 1923 he lived in France where he succeeded in making known his “ultrachromatic music” played on two pianos that had been tuned a quarter of a tone apart. His aim was to create a sound continuum, that is, a universe of sounds and rhythms symbolizing the cosmic consciousness of man. In addition to executive and instrumental aspects, Wyschnegradsky devoted himself to inventing an adeguate representation of his ultrachromatic compositions for notation on staves. He also contemplated a notation “in colour”, substituting the symbols of note alteration with colours; this chromatic vision was intended to simplify the reading of the notes [13].

Wyschnegradsky had attempted an audio-visual synthesis, conceiving a space with a circular groundplan surmounted by a hemispherical cupola on which figures made with the 6 colours of the rainbow and 6 intermediate colours would be projected. These projections would have formed luminous coloured shapes animated by a movement in harmony with the music. The dimensions of the space were the following:

- external diameter of the cupola (12x10)m = 120m
- internal diameter of the cupola (12x10)m – 12m = (120-12)m = 108m

This space, called the “temple of light”, represented a symbolic image of the musical and cosmic universe (Fig. 1).

In 1943 Wyschnegradsky began to elaborate a series of coloured drawings representing musical compositions called “chromatic studies” (études chromatiques) [14]. The drawings are formed of circular shapes divided into 5184 coloured cells, the colour representing the height of the sounds of a piece (Figs. 2, 3, 4). Each chromatic study could “compose” different pieces according to the starting-point and route taken on the drawing for the “reading” of the coloured tiles. This representation created a total analogy between music, space and colour, despite the fact – as the author himself declared – it was based on three compromises: colours instead of lights, immobility instead of movement, a circle instead of a hollow hemisphere [9]. That is, the passage from a three-dimensional idea of a musical event to its fixed two-dimensional representation (Fig. 5).

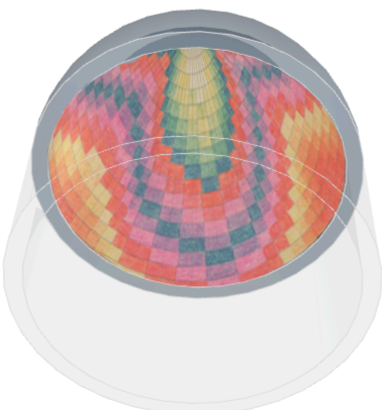


Fig. 5 – Hypothesis of projection of a Chromatic study on the dome of the del “Temple of light” , perspective from the bottom upwards (processed by the author).

6. The case of Lombardi

Daniele Lombardi (1946-2018) was a pianist, composer, scholar and critic of contemporary music, particularly futurist music, which he also played, taking it out of the archives and putting it back on stage. He was also a visual artist and performer, placing great emphasis on the visualization of gestures, colours, musical marks and notations (Figs. 6, 7).

The reason we are interested in taking his visual work into consideration here is because his "music for eyes" aimed at the creation of a process that was contrary to the one hitherto described. Lombardi believed that the avant-garde idea of synesthesia between vision and music was a mere utopia, given that "the space-time of sound and the space-time of vision, although complementary, belong to two different worlds that develop different conventions" [15]. He wanted, therefore, through his highly personal representation of music made up of combinations of marks and colours, to make it possible for a musician to bring his own contribution to the interpretation of the marks, seeking inspiration in his own inner space, imagining the music filling that inner space, generating a spiritual dimension and stimulating a part of the mind in which abstract formulations move.

The execution of this music for eyes also requires a physical spatialization necessary for the unfolding of the sound event, and is closely linked to the setting up of the drawings inside spaces that can vary with each performance (Fig. 8). The strips bearing the drawings, depending on their colour, chromatic intensity and position on the score sheet, are thus interpreted musically and spatially by the performers of the piece in a way that is personal, although certainly not arbitrary since Lombardi's markings have rules of interpretation that he himself indicated.

Fig. 6 - Work by di Daniele Lombardi.

Fig. 7 - Work by Daniele Lombardi.

Fig. 8 - *Musica Virtuale 22* by Daniele Lombardi, music score set-up at the Bowling of the Fattoria di Celle (Gori Collection), 2016.

7. Conclusions

Arts like architecture and music are very strongly linked to images, even virtual ones. Thanks to new computer potential, artistic expressions can express creative factors with increasing ease: mental utopias are converted into navigable spaces, opportunities to experience virtual realities linked and attributed to the various expressive manifestations of human fantasy have multiplied. Technical limits that existed in the 20th century have been superseded, making way for any type of "synesthetic" application; these are as easy to create as they are – often – devoid of any real knowledge behind the deeper significance and control of the combinations formulated automatically on the screen.

This is but an initial approach to a field of research that promises to be extremely interesting: presenting this overview of the subject has opened up a large range of possibilities not only in theoretical terms but also as regards the three-dimensional repppresentation of these journeys of imagination.

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The harmonies of colours in the underground spaces of the city

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1. Introduction

The harmonies of colors in the visual environment of underground spaces compose and draw the attractiveness and polychromy of life and of the underground part of the city, highlighting its invisible axes.
Psychological and visual adaptation is unavoidable in confined spaces. This adaptation is possible thanks to chromatic creations in tunnels of public transport, subway stations, underground gangways or covered walkways.
Art and modern design (underground public transport stations, walkways, shelters) by their chromatic harmonies and luminosity produce a specific effect, even more differentiating, organized and amplified by the shapes and chosen colors. They are an essential part of the ecological color strategy. Their color codes vary according to their disposition, according to different points of view and different situations.
The aesthetics of the visual environment of underground spaces is an essential component of its identity; the combination of colors and lights creates the sixth façade of the modern city that is responsible for promoting the security and serenity of its citizens.
Today, the image of the underground space is not seriously taken into account in the project of colour design of the city for several reasons. Yet, throughout history, man has always sought to beautify of the underground space, whether living in caves or underground spaces in medieval troglodyte cities, or, more recently, environment of transport infrastructure. The underground city of the 21st century aspires to a more intense development, rich of various functions and in which the inhabitants of the city will spend more and more time. In this perspective, the subsoil represents a real potential for densification for the city by participating in the rationalization of space and the development of new uses. The development of the underground space will have two aims: to promote a compact city and preserve environmental quality.
Color is certainly the most popular of aesthetic feelings and the one that brings more than 90% of information by visual perception. The chromatic identity of the environment has long been an important visual message. Material colors are essential components of spaces and enrich the atmosphere of the underground city by giving it meaning and simplifying the orientation.
The color harmonies in the underground spaces compose and draw the image and the identity of the underground city, highlighting the axes of orientation.
Psychological and visual adaptation is more difficult in enclosed spaces. It is possible thanks to chromatic creations in transport tunnels, metro stations, underpasses or covered passages. Art and modern design, with their chromatic harmonies and artificial brightness, produce a different and organized effect. The aesthetics of the visual environment of underground spaces is an essential component of its identity; the combination of colors and lights creates the sixth facade of the modern city that must promote the security and confidence of citizens. We want to propose concrete

measures and ways of working to adopt a system of visual codes of color, so we made an inventory that allows us to present today the specific and original pallets in the known international practices in this field.

2. Objective

In order to create original spaces, visually comfortable and adapted to the conditions in situ, it seems important to analyze the evolution of artistic means, techniques used, materials (colors - materials - lights) and chromatic harmonies. Thus, it will be possible to respond with great care to the problems posed by the image of underground spaces. With its multiple nuances and complex combinations, it is a rich phenomenon, it participates in the expression of a culture, it establishes the relationship between modernity and history, aesthetics and architecture. Art and Architecture, new technologies and communication, industry and physics, psychology and sociology - all these areas come together.
Chromatic harmonies are not just images, lines or spaces: they are the expression of plastic ideas in a given context formed by underground spaces; they evoke symbols and arouse emotions. Architectural polychromy is the visual aspect of the construction, made as much by the use of natural materials (stone, wood) as by that of applied layers (painting, mosaic, the use of metals, ceramics) . The specific atmosphere, created by the color combinations, can transform the environment and produce psychologically favorable or unfavorable perception conditions: it can be the source of a harmony and a visual equilibrium, or enter into contradiction with the context natural landscape and provoke real catastrophic "visual pollution" and cause melancholy.
It is important to study how artists and architects from different eras and cultures have considered color harmonies in the architecture of underground spaces.

3. Cultural developement and history of color in underground spaces

The history of color in underground spaces begins as early as the Paleolithic. The paintings of Chauvet go back to a period between - 30 000 years and - 28 000 BC, those of the Cave of Niaux dating back to the Magdalenian period, between -18 500 and -10 500 years, and Lascaux - 17000 years. The sets of these graphic and chromatic compositions (animal or geometric, grouped or isolated) are dispersed in the cavern space but are not randomly distributed. These are topographical and spatial landmarks in these deep galleries. They appear placed according to certain peculiarities of the relief and the morphology of the space. The homogeneous atmosphere of these closed sacred places was dominated by gray and ocher, sometimes enhanced by red, green ocher and brown, depending on the local peculiarities of the earth, sand and clay, and that according to those special binders added to the clay mass.
The idea of valuing the underground space comes from very ancient civilizations. In the times of ancient Egypt, the tombs required a decorative treatment of surfaces, because it was a civilization characterized not only by its love of life, but also by its belief in eternal life. The harmonious architecture and chromatic rhythms of these sanctuaries are composed of images on all the walls of the ensemble. The beautiful

apparent unity of these subterranean spaces is not only the result of a thoughtful plan implementing a pre-established symbolic construction, but the ultimate result of separate actions, staggered over time during different ceremonies.
The beauty of sites such as troglodyte sites and underground spaces is different in separate cultures, be it in the Nabatean capital, in Petra in Jordan, in Üçhisar, in Cappadocia in Turkey, in the Wieliczka salt mine in Krakow, Poland, or at several sites in America, Mexico (Puebla). It is surprising in China (the ancient Caves of Longmen as the modern city Dìxià Chéngcité under Beijing), India (Bhubaneswar), and Sri Lanka (Golden Rock Temple Dambulla) (Fig.1).

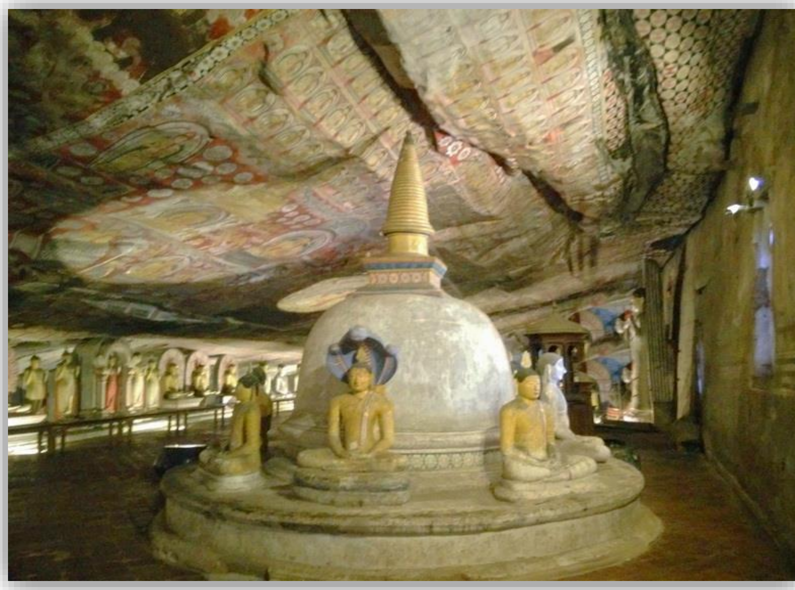

Fig.1. Golden Temple of Rock, Dambulla (Sri Lanka)

It reveals neighborhoods with different functions including permanent or temporary habitats, refrigerators, shelters for an army of defense, religious functions (shrines, necropolises, graves etc.). Their beauty is each time original and linked to the geographical range of the place. Sometimes there will be similarities in the image given by very distant undergrounds, such as the Bachkovsky Monastir in Bulgaria and Matera in Italy. In Matera, the troglodyte underground churches are richly decorated and painted, sometimes surrounded by a small monastic complex (refectory, tombs, etc.) The paintings were either directly applied to the rock, in which case they were often less sophisticated and in the colors red, or applied on a layer of plaster previously whitewashed on the walls. The colors (plant pigments) were then much richer. Underground and troglodyte cities are also known in France.
From the eighteenth century, we are witnessing the emergence of the concept of underground urbanism in France. The first consideration of the underground space, in

Paris, dates from 1774. The General Inspectorate of Quarries was created in 1777, following a collapse around the current Boulevard Saint-Michel. Studies have been undertaken to better understand the underground spaces of the city, to map and consolidate them. Eugene Hénard defined the concept of the multi-storey street in 1910, and architect Édouard Utudjian created the underground urban plan in 1930: it was designed in correlation with the "general" urbanism. The basement appears as the "hidden face" of the territory. It can accommodate a significant share of urban functions and services. It is necessary to plan the uses of the subsoil, which is considered an integral part of the overall urban space, in space and time: "There is deep planning to invent," said Utudjian («Architecture and urbanism underground", Robert Lafont, Paris, 1966).

Fig.2 -The metro station Toledo, Napoli (Italy), price LEAF 2013

The architectural and chromatic conception of modern underground spaces as well as that of the different historical contexts is characterized by three main parameters:
1) the activity or passivity of the contrasts between the elements of the composition of the colors;
2) the degree of independence of the color in relation to the volumes and the spatial and architectural particularities of the form;
3) the modes of interaction between color and architectural structure with respect to space.
The polychrome of underground spaces draws this part of the city, highlighting its circulation axes. This visual environment is composed by harmonies of colors, light and materials that allows us to identify and guide the user. (Fig.2.) It also allows to

"humanize" and harmonize the urban underground space, it gives a sense of comfort. The plastic and symbolic expression gives a new visual identity to the city and its underground spaces. The international study of existing practices will help us to understand the working approach, to propose strategies and to establish a color code for the different types of spaces in order to favor the visual comfort and the safety of the citizens.

To carry out a study of the specific and original palettes of the underground spaces in different cities of the world, we used the method which allows an analysis at the same time environmental, scientific, artistic and psychological. This interdisciplinary analysis, based on observing and decrypting visual codes, allowed us to create the system of harmonies / color associations.

The results of the study of international practices (France, Italy, Portugal, Belgium, Spain, Sweden, Russia, Czech Republic, Argentina, Japan, China, Australia etc.) show the originality of chromatic harmonies in relation to different cultural and geographical contexts (Fig.3,4,5). We can distinguish 4 main groups and 24 complementary intermediate groups of color association.

They are represented using the NCS color system - Natural Color System - Natural System of Color, chosen as the analytical instrument. Chromatic solutions for today's underground urban spaces improve and humanize the image of this backside of the city. This is particularly important for subway underground passages, which are transformed into stations, sports or aquatic centers, car parks, shopping malls or cinemas...

Fig.3- Metro station Kungsträdgården, Stockholm (Sweden)

4. Create and offer high quality underground spaces providing visual comfort.

What is the future of underground spaces in the polychromy of the urban environment? Will the underground spaces be a compilation of art or will be a support for an artistic experiment? Will they be neutral without personalized writing or composition highlighting the identity of the place, and simple media of many endless commercials?
We propose an analysis of the visual ecology and an environmental strategy by the color in the underground spaces of the city, based on the chromatic study.
The chromatic image of the underground city is rooted in its geographical space but changes over time: it changes with the rhythm of the evolution of urban planning and is changing. If all the visual elements of the subterranean space, the color remains an essential element of its architectural, cultural and social environment.
Today, an underground city aims to offer the inhabitants a quality framework respecting the landscape environment and the local culture of the architecture of its own.

Fig.4-Connexion between interior and exterior space: metro station Abu Dhabi (United Arab Emirates)

This is why the reflection on the sustainable city needs a chromatic strategy of the environment. At present, designing color in the underground spaces of the city is part of new ideas and innovations in underground urbanism. In the choice of colour codes and chromatic harmonies can revitalize this space by promoting a sense of security and comfort among citizens. The result is a color ecology, a major component of the environmental project that must be included in the city's sustainable development

project. This approach is of interest to architects and designers for whom it seems obvious. It allows to identify the visual "genetic inheritance" and to create palettes respecting the "genius of the place" because it is based on the analysis of the key harmonies of each place, in connection with the spatial conception, which studies the interaction of the colors with architectural forms and the composition of space.
This approach is also social since it takes into account the preferences of the population. The enhancement of the accents or dominant visuals makes it possible to break with the feeling of isolation and that of disproportion. This environmental strategy allows continuity in the perception of the underground city: it is necessary to analyze the overall image of the underground city, then of each of its neighborhoods, then of each of its stations, being attentive to the design of street furniture, landscape qualities, the artificial lighting of transitional spaces between underground spaces and the outer city.
All this must have a chromatic coherence to be able to form a harmonious whole. Just like an ecological system, this strategy will avoid cases of visual pollution (which does not do less harm than those of air pollution, water or noise), but this program will also make it possible to repair the errors of the past and to revalue the image of ancient spaces by harmonizing contemporary interventions with it. It will create a good quality chromatic environment for new underground centers by integrating new national and international cultural contributions and leaving the door open to creation. The color of the underground city, rich and complex, animated and full of meaning will participate in the image of the city of the 21st century, more sensitive and moving. The results of investigations devoted to the chromatic image of the underground city will thus be an indispensable part of the training of architects, designers and visual artists.
To ensure a high level of architectural and environmental quality, the "Ecology of Color and Environmental Strategy" program is developing a series of color studies that can create a coherent and aesthetic visual system for buildings and developments in the city. This approach proposes to develop large "reference areas", to make these zones radiate in the city by "concentric zones", and finally to compose characteristic entrances by the "made-to-measure" color palettes.
The methods for the chromatic conception of cities and territories are described in a book published by "Le Moniteur" in 2008, entitled "Color in the city". The questions of an "ecological approach" of color in architecture in the twentieth-twentieth century are treated in a book, "Symbolic. City in Color "," Eighth Day "edition, published in 2010, which includes an analysis of international practices recognized for their positive effects (in England, Canada, Sweden, Germany, etc.) [1], [2].
Color in harmony with the light and the tactile qualities of the materials, is essential in the spatial composition, with the metric, rhythmic composition, the modular and proportional suites, the symmetry of the structures, or the formal contrasts. It is obvious that it can not be the result of chance. On the contrary, sustainable action on environmental projects is necessary. That is why we are proposing a working method that has already been successfully tested in some European and non-European countries.
The ecology of color is a reasoned strategy aimed at creating a balanced visual environment of chromatic harmonies for users of the underground city.

This approach aims to rediscover and promote a unique atmosphere in each underground space. It does not forget the part of contemporary creation nor to involve the artists and the landscape to ensure the durability of the visual qualities.
The harmony of the built environment, the visual ecology and the aesthetic qualities of cities are important factors for well-being. Underground spaces at present need an aesthetic organization as they need an organization for transport, energy or telecommunication. This is why today more than ever, the question of respect for the environment must include the question of the harmonization of visual components of the underground city. Such approach determines the quality of the living environment and the visual ecology of the urban environment. Two phases of work are required.
During the first phase of design, the colorist-consultant develops a methodological note. This phase consists of conceptualizing a global color scheme. The colorist architect will implement a color chart to create a visual identity that will respect the image rendered by the architectural elements. This charter will highlight the existing sets of elements by encouraging the respect of a consistent harmony in the use of colors and materials supports.

Fig.5 - Connexion between interior and exterior space: metro station Mar-city,Tokyo (Japon)

The second phase is a consulting assistance mission. The colorist-consultant architect proposes a chromatic plan in operational phase. The colourist undertakes to prepare the chromatic project that will be included in the urban project management. For a prolonged period, the architect-colorist-consultant will also intervene on the projects of repair or improvement of the existing underground space, helping to the integration of contemporary architecture marked by the use of new coating materials and by applying a new color palette. It remains open for all forms of cooperation: in-depth diagnosis, expertise, consulting, projects, and chromatic study.

Conclusion:

The aesthetics of the visual environment of underground spaces is an essential component of its identity; the combination of colors and lights creates an atmosphere that promotes the feeling of security and serenity of citizens.

The reflection on the sustainable city must be enriched by the development of a strategy for the chromatic design of underground spaces and their visual environment.

The components of the visual environment of underground spaces are part of the image of the city and are always changing and evolving. New ideas induce reflections and show possible innovations. We propose to consider the following Action Program:

1.) Update knowledge on the visual environment of underground spaces and their local characteristics.

2.) Consider the study of colors as a major part of the environmental project and control its choices.

3.) Include this study in more general objectives of sustainable development and European project of high environmental quality - HQE.

The intelligence of a system of colored codes for the visual environment of underground spaces is a source of urban revitalization.

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Millennial pink: From iPhone to Rihanna
An Analysis of a Color Trend

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1. Introduction

The millennial pink is a new shade of pink, a color trend which appeared in late 2015. It is called "millennial pink" because it is particularly aimed at a generation of young people born between 1980 and 2000, who masters new technologies and especially the Internet on which they spend their time. Fashion journalist Véronique Hyland gave its name to millennial pink in an article published on *The Cut* website on August 2, 2016. She indeed noted that a wave of pink had invaded both the world of fashion and the world of design, which was obvious on social networks, leaded by Instagram [1]. The millennial pink quickly became a true fashion phenomenon used in haute-couture (Gucci, Balenciaga, Valentino, Calvin Klein, Chanel, Anya Hindmarch, Peter Pilotto, Ryan Lo, Victoria Beckham or Helmut Lang) or ready-to-wear (Puma, Nike, H&M, Reebok, Chloé or Common Project). It also reached the sphere of design and architecture, previously influenced by the emergence of "Scandinavian Pink" in Nordic furniture, and in particular those created by Normann Copenhagen. The millennial pink trend then reached the world of *fooding*, *Instagram* brimming with photos of rosé and rosé cocktails, as well as beetroot, strawberry, pitaya and other radish dishes. This strong influence emerged along with the release of a new kind of pink chocolate (food coloring free), the "ruby chocolate," and the success of the pink salad. Finally, the craze for the millennial pink had repercussions on tourism. For example, the Australian Pink Lake became a very attractive destination for millennials.

Fashion journalists face difficulties when they attempt to describe the millennial pink, mostly it is actually not a color, but it is a set of shades of pink, a color chart of pale pink, beige pink and salmon.
More than a color, the millennial pink is above all an idea, accordingly with Michel Pastoureau's understanding of the colors first as concepts, then as ideas and finally as intellectual categories [2]. The millennial pink is a new approach to pink: since it is no longer referring to the twentieth century's symbolic of gender, pink is now seen as a positive color [3]. Therefore, the millennial pink is not a new pink. It is a sub-category of pink, grouping a set of hues that dissociates itself from the archetype caricature of femininity while moving away from the princess or Barbie pink. This is why its pale hues are pushed away on indefinite corners on the chromatic spectrum. They end up with colors considered as « neutral » regarding gender, such as white, beige, orange or gray.
Also, the millennial pink is a non-feminine pink, a "not-pink pink", and it is on this concept of "neutral" pink that the success of the millennial pink is built, playing on the contrast between traditional femininity and feminist femininity, and that of a feminine color and virile masculinities.

Fig. 1 - Color chart of millennial pink. It was obtained from the collection of one hundred images answering the keyword "millennial pink" on the internet, in September 2017.

2. Short "history" of Millennial Pink

Because it corresponds more to zeitgeist than to an object in particular, it is difficult to trace what would be a "history" of the millennial pink. Nevertheless, there are events that, for one or another reason, have been considered *a posteriori* as important elements of the trend. This recent "history" consists of a relatively large amount of events that follow one another or overlap each other, which are mainly relayed on the Internet.

The internet is a place that promotes the development of micro-trends, both musical and visual. For a few years now, pink has started to dominate the web, especially via the *Tumblr* website, to the point where we are able to talk of a "Tumblr Pink". First, with the emergence of the seapunk movement [4], and then with the vaporwave [5], a micro-genre of electronic music that develops in parallel a visual aesthetic where pink holds an important place.

But if they are productions of the younger generations, the pink in the seapunk and vaporwave is not associated with a gender symbolism: it is used to contrast with the dominant blue of the first movement, and it evokes the artificiality of the virtual worlds in the second movement. Pink on the Internet emerged simultaneously with a popularization of feminism, with personalities such as Beyoncé, Emma Watson or Miley Cyrus, along with the re-appropriation of the pink color by young feminist artists (the “radical softness”). It then acknowledged its feminist potential that would lead to the millennial pink.

Fig. 2 - example of a visual “vaporwave” by Raphaël Dong, circa 2016-2018

2.1. How iPhone “rose-gold” subverted masculinity

The release of the “rose-gold” color of the iPhone 6S, Apple's latest smartphone model in September 2015 is considered the first true occurrency of the millennial pink, when signifying clearly that the color would not be a regular pink, but a totally new one. Completing the already existing colors (“gold”, “silver” and “space gray”) the rose-gold iPhone had the ambition to appeal to an Asian clientele — and in particular Chinese — who values gold tremendously. Nevertheless, the rose-gold iPhone found his audience in the West, among young women who see in this model a feminine version of the smartphone; but also with some young men, more hesitant to buy it for fear of seeing their masculinity stained by the possession of a pink accessory.
Very quickly, this new color challenged the Internet, because Apple seemed to offer for the first time a smartphone to only one part of the population: women. Since colorful objects are strongly associated with the feminine in the West, the men who *dare* to wear pink clothes or to have pink accessories are still few. This new color is considered too feminine and not manly enough, and very quickly, media and web forums asked themselves the question: can men have a pink iPhone?
The choice of color in marketing, whether in terms of product, packaging or communication, has a great influence on consumers. Pink is massively used as a signifier of femininity and is applied just about every marketable product. By targeting a female audience, the pink product keeps, at the same time, the male clientele away. Therefore, during the designing conception of the product, the customer’s gender is

always addressed, and it is strongly recommended to ban pink if the target audience is a male clientele [6].

Fig. 3 - iPhone 6S, “pink-gold” model, promotional visual Apple, 2015.

However, “rose-gold” is not really pink since still falling in a metallic color, and because such hues refer to technology and therefore to masculinity. The rose-gold iPhone is claimed for men a way of being masculine. “Men, do not fear the rose-gold iPhone” headlines an article from the *Wall Street Journal* [7], while a developer of the social network Twitter, says: “There's enough guys getting pink gold that it should be called bros’ gold” [8].
“Bro” is a diminutive of “brother” and refers to masculinity, which reassures the consumer that the purchased product is for him. It also refers to fraternity, underlying a solidarity between all these men who *dare* to buy this “subversive” model, and to go against the chromatic codes of traditional masculinity. The purchase of the rose-gold iPhone is no longer a question of taste or preference for a color, but it becomes a political choice and an identity reaffirmation of manhood by the integration of these circles of male customers. They are not only supportive, but also brave, and therefore equally virile.

However, this subversion is no longer really one: by changing the name of the color from “pink” to “bro’s,” the color is disconnected from its feminine symbolism. If pink is well accepted as the color of the feminine, the “bro's gold” becomes “the gold of men.” Moreover, gold is not even a color but a material. Therefore, since it symbolizes wealth and power, the very name of the color embodies men’s clichés. Pink is now intended for an exclusively male clientele with a speech and terminology that eradicates any possible closeness with the feminine gender.

2.2. The Pantone propaganda

Since 2000, Pantone chooses a “Color of the Year” based on a multimodal trend analysis. The trends are strongly influenced by the “Pantone propaganda” [9], and Pantone's “Color of the Year” reverberates on the worlds of fashion, design and graphics, wether immediately or a few months later.

Extraordinarily, the 2016 winner is not one, but two colors: Pantone announced on December 3, 2015 that “Rose Quartz” and “Serenity” (a shade of blue) were elected colors of the year. According to the executive director of Pantone Color Institute Leatrice Eisemann, “Serenity” is “weightless and airy” and complementary to the “Rose Quartz”, a “persuasive yet gentle tone” that expresses “compassion and a sense of composure” [10].

Fig. 4 – “Rose Quartz” (PANTONE 13-1520) and “Serenity” (PANTONE 15-3919), elected Color of the Year 2016 by Pantone

But beyond their relaxing qualities and the visual contrast that is played between these two tones, it is the pair of colors traditionally gendered in the West that we are dealing with: the blue of boys and the pink of girls. However, the press release announcing the election of the duo “Serenity”-“Rose Quartz”, claimed an overcoming of the sexual dichotomy by the appropriation of its chromatic symbols.

These “Colors of the Year” 2016 would echo the social movements towards gender equality, transgender people rights and gay marriage. Pink and blue would become the emblem of a younger generation supposedly less inclined to categorization and open to gender fluidity. The emergence of gender neutral or non-binary people's claims movements made popular by celebrities like Miley Cyrus would be a proof of this achievement.

Then, “Rose Quartz” should be understood as subversive, since it shifted the popular view on pink by splitting with its feminine symbolism to make it the very color of feminism, of the equality of the sexes, even of the neutral. To do so, its association with the world of little girls and princesses must be relinquished in order to achieve a renewal.

3. Pink, gender and marketing

3.1. When Rihanna sells feminism

The brands seized the acknowledgment of pink as the color of feminism, even post-feminism. Feminism is now a part of marketing strategies. “Femvertising” consist in using feminism to sell, by exploiting the feminist concept of empowerment, by playing with gender stereotypes using a queer aesthetic, or by reclaiming the codes of girl power.
Therefore, popular figures such as Rihanna, who holds strong feminist positions, do not hesitate to appear in pink. In September 2016, the new collection “Fenty x Puma” introduced by the collaboration between the sportswear brand and the singer was born. She surfs on the millennial pink wave and presents many models wearing pink clothes. The clothing is inspired by the eighteenth century. It resets the flagship color of the Rococo, and also uses fabrics such as lace or chiffon, strongly associated with the feminine.

Several feminist movements of the 2000s also took up the pink as a symbol of political demand. The Gulabi gang in India, a group of women formed in 2002 by Sampat Pal Devi, campaigned against domestic violence against women. They adopted pink sarees to be singled out as members. Or the “pussyhats,” an American movement of feminists who demonstrated against the presidential campaign of Donald Trump, and whose distinctive sign is a pink woolen hat in the form of cat ears. These feminist groups are creating a shift in the feminine stereotype of pink from gentleness and passivity toward force and rebellion. By mixing a very feminine and stereotypical aesthetic with a line of sportswear clothes, Rihanna also tries to show that one can be feminine and sporty, or feminine and live in the middle (sportswear being also a mark of class).
Rihanna uses here the concept of empowerment developed by feminism to make a marketing surplus for her collection, and for the brand Puma: one can be a feminine woman and have so-called male activities or characteristics. The pink initially used in gender marketing to decline a product line in a line dedicated to women, becomes here a feminist marker, pushing women to choose the pink product because it is feminine, and no longer to select passively because the products for women are usually pink.

Fig. 5 - Promotional photography of the “Fenty x Puma” Spring-Summer collection, 2016

3.2. Can the pink be masculine?

But what makes the communication force of this collection is that pink is also chosen for men's products. It's really by combining masculinity and pink that brands are best at attracting attention. Indeed, the contrast between the association of a feminine color and masculine figures attracts the eye while conveying a queer message of displacement of the stereotypes. For example, German artists EVA & ADELE, “*the hermaphrodite twins from the future*,” [11] have made pink the emblematic color of their gender subversion. The French artist Marcel Duchamp chooses “Rrose” as a name for his feminine alter ego created in 1920, both anagram of Eros, but also the color of ambiguity incarnated by Rrose Selavy.

Pink was used by the Nazis during the Second World War and its re-appropriation by gay communities make also pink a color of ambiguity and homosexuality [12]. Indeed, by becoming the feminine color, pink has become an anti-masculine color, which, when associated with a man or a boy, may cause an alteration of his manhood and creates a suspicion of homosexuality. It can also lead to homophobic reactions, sometimes violent [13].

The question of whether men can wear pink is not new, and the contrasts between men's and women's clothing are fading, including the gender segmentation of pink for girls [14]. According to Leatrice Eisemann, the gender division tends to fade in fashion, which would coincide with the social movements that have been moving toward gender equality since the 1970s. Because it splits with the feminine connotations usually associated with pink, the millennial pink is considered as the “new neutral” and perceived by several media as an androgynous or unisex color.

If the media are not slow to take an interest in Zayn Malik's pink hair, the appearance of Drake with a pink jacket, Justin Bieber with a pink hoodie, or Kanye West who often appears in pink, the extension of millennial pink to the male wardrobe is seen by some media as a feminization of men's fashion, a movement from feminine to masculine often at work when it comes to unisex fashion.

4. The color of the buzz

If the trend of the millennial pink took so much scale and evolved so quickly, it is because the idols of millennials, very active on social networks, play with this trend too. They drain around them a stream of media relaying their adherence to the fashion of the moment. Any appearance of a star in pink is subject to “buzz,” that is to say, a viral media communication that focuses all the attention, especially on the Internet, for a very short period of time. It is a vivid promotional tactic for the media. When they publish their articles, they get the number of views needed on their pages to be adequately paid by advertisements. In the meantime, artists draw attention to themselves and to the products they potentially need to sell.

If Zayn Malik chose Valentine’s Day to appear on his Instagram account with pink hair, it is mainly because he intended to draw attention to him after the release a few days earlier, January 29, of his debut single, “Pillow talk,” from his first solo album *Mind of Mine*. Still, Charli XCX's “Boys” video might not have been as successful if it did not show men dressed in pink and doing so-called feminine activities such as washing dishes, participating in pajamas party, or cuddling a stuffed animal.

Fig. 6 - Charli XCX, “Boys”, 2017. Screenshot

In addition, pink is generating interest in terms of communication: it attracts the eye as much as it arouses curiosity. According to a first study, pink tones attract more attention than more saturated shades or than blue or green shades [15]. Another study shows that in the specific context of the Internet, red, purple or pink images, have a better chance of being propagated on *Pinterest* social network [16]. Obviously, this is a marketing and communication property of pink that greatly benefited the millennial pink.

A brand like Acne was able to own the benefits by adopting a pink powdered visual identity in 2007, before the golden age of the trend color. When walking the street with a tote bag from Acne, the customers catch the eye on them, and thus contribute to promote the brand. An increased phenomenon when it comes to male customers, since the chromatic contrast doubles as a symbolic contrast, which not only attracts attention but also spreads the values of a brand who seems to want to break the gender roles.

5. Conclusion

If young people mostly give in fashion trends, then not necessarily follow the same ones. Moreover, if they share a certain number of common traits (integration of the Internet in everyday life, presence on social networks as *Facebook*, *Instagram* or *Snapchat*, sensitivity to feminist theories, etc.), the generation Y is in no way a homogeneous whole. Social and cultural disparities differentiate the millennials [17]. We can therefore wonder about this globalization of a generation represented by a single “pink flag.” If Pantone ranks colors behind the declared values of gender division, we must keep in mind that fashion has always made gender division a central concern [18]. Fashion is a product of class division and is primarily intended for elites [19].

Moreover, if the millennials live in an era that legalized same sex marriage and brought transgender characters to television, with shows such as *Sense 8* or *Transparent*, it is also a generation that has seen the rise of conservatism and even extremism in several countries. Also, debates around gay marriage revealed that homophobia was rooted in different strata of society.

The recovery of millennial pink and its so-called feminist values by brands is only the development of a new form of gender marketing (the femvertising) that uses a fashion movement to generate profits, proceeding in the same time to its depoliticization [20]. By standardizing a generation under the same banner, Pantone's trend erases the inequalities between individuals and presents gender equality as an achievement reached by all, which is not yet the case.

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Translating Colours – A Cognitive-Linguistic Research Project on Translating Colour Words and Colour Metaphors into Estonian

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1. Introduction

Translation of colour terms is an interesting research topic, engaging both for cognitive linguists and translation scholars and practitioners of any other field who have ever came across a need to find appropriate equivalents to express colour in a foreign language. It may seem fairly easy to translate colour terms from one language into another. However, colour is often a culture- and language-specific concept and finding appropriate equivalents in both target and source language which correspond to each other in a neat way, should not be underestimated.

Without doubt, most difficult cases of translation of colour terms include the ones where no one-to-one correspondence in any language other than original can be found, such as Italian *azzurro* [1], [2], [3]. It is difficult to find an appropriate translation equivalent for culturally loaded words as *azzurro*, since translation equivalents usually do not share all specific semantic connotations and associations in other languages (see [4] for discussion). Some find it easier to leave colour words in the original language in a text rather than seeking the appropriate translation equivalent which might still be misleading, despite the best endeavours of the translator, or might carry different connotations in the target language.

The phenomenon of metaphor has been widely discussed within the discipline of translation studies, predominantly with respect to translatability. It has been argued that metaphors can become a translation problem, since transferring them from one language and culture into another may be hampered by linguistic and cultural differences [5] p.1253. Bennett emphasises that this is especially difficult considering colour metaphors as different languages identify different things around us, filter our experience of them, and characterise these things differently [6] p. 273.

The aim of this study is to investigate how volunteer subjects, some of them employed in the translation industry and some otherwise employed, translated separate colour words in a context-free condition and colour metaphors into another language. As the main body of research was carried out on English into Estonian translation, 20 volunteer participants also translated colour terms from Italian into Estonian. The latter case constitutes an especially interesting case, since Italian colour categorization differs from that of Estonian, having two separate categories for the blue area, since the system of English could fairly well be mapped into Estonian. Our research questions include how colour terms and colour metaphors are translated, how different language-specific or culture-specific colour terms which do not have a one-to-one equivalent in any language other than the original may be translated and whether we can discern a difference between professional translators and non-translators based on qualitative analysis. More precisely, we focused on translation strategies that were used, differences in colour words and phrases translated by professional translators and non-translators, by male and female participants and possible difficulties that emerged during the translation process.

Due to a relatively small male sample for both tasks we are not able to ascertain differences between male and female translators.

2. Methods

A cognitive empirical research was carried out with separate groups of participants (see Tables 1 and 2). Some of them translated only single colour terms, whereas others translated single phrases containing colour metaphors. All tasks contained basic (e.g. *red*) as well as non-basic object-related colour terms (e.g. *emerald*) and non-basic colour terms from semantic shift (e.g. *silver*).

2.1. A method of translation of individual colour terms

The first study, so-called colour word translation task, was conducted with two language pairs, English-Estonian and Italian-Estonian. In the first study, participants were requested to translate context-free colour terms into their native language. The English-Estonian sample consisted of 20 participants (as shown in Table 1). All were native speakers of Estonian with a range of social, educational and linguistic backgrounds. The sample consisted of translators, some with little experience and some with a lot, whereas others did not have any translation experience. The subjects self-reported their knowledge of the foreign language which was used as the source language, English or Italian, as B2–C1 in the Common European Framework of Reference for Languages (CEFR). All the experienced translators had been trained in translation. The less experienced translators self-reported that they had no more than five years of translation experience, while the experienced translators had translated novels or technical, legal or economic texts, or were specialists in audio-visual translation or localization. Participants were not informed about the specifics of the task until the immediate beginning of the test.

	Group 1	**Group 2**	**Overall**
Language pair in the task	Italian-Estonian	English-Estonian	
No. of participnats	20 (3 male)	20 (5 male)	40 (8 male)
Age range	19–60	19–58	19–60
Experienced translators	7	8	15

Tab. 1 – Participants who translated individual colour terms

The colour terms selected for the Italian-Estonian context-free task were extracted from colour naming data collected in Florence in 2006–2008 [7] and were the following: *blu*, *viola*, *azzurro*, *fucsia*, *lilla*, *indaco*, *turchese*, *verde smeraldo*, *amaranto*, *porpora*, *verde acqua*, *verde Veronese*, *scarlatto*, *terracotta*, *granata*, etc. The English-Estonian word-translation contained 17 words which were derived from object names and were selected from Seija Kerttula's monograph on English colour terms [8], e.g. *rose*, *ivory*, *lemon*, *coral*, *lilac*, *chocolate*, etc.

2.2. A method of translation of colour metaphors

In the colour metaphor translation task, participants had to fill in a paper-based or online translation task including 21 English colour metaphors that were asked to be translated into Estonian. After translation task the background questionnaire was filled in by the subjects. It contained questions regarding age, proficiency in language, but also inquired whether they had lived in an English-speaking country. Questions also referred to problems that occurred during the test. Forty-five volunteers took part in the study (see Table 2 for details). One of the aims of the study was to analyse whether professional translators had different results from the participants with no previous knowledge about translation.

	Female	Male	Total
Translators	29	4	33
Non-translators	6	6	12
Total	35	10	45

Tab. 2 – Participants of the context-free study of metaphor translation

All participants were L1 Estonian speakers. The main criterion for eligibility was C-level proficiency in English based on self-assessment. Translators in the sample were people with no less than 2 years of translation experience. One fifth of the sample had lived in an English-speaking country for an average of 2 years and 8 months (countries of destination included United States, United Kingdom, Australia, Canada and Ireland).

3. Results

Several examples from our database illustrate both cultural differences between languages as well as the importance of context in translation, e.g. a *yellow-bellied person* in English can become "someone with a fat belly" in Estonian.

As not all translation strategies are suitable for either colour word translation or colour metaphor translation, a classification was compiled in order to conduct a descriptive analysis on colour word and colour metaphor translation. Translation strategies to analyse the results of the study were the following:

- reproducing the colour word/colour metaphor in target language with a (coequal) colour word/colour metaphor;
- replacing the colour word/colour metaphor without a colour word/colour metaphor in target language;
- converting colour term/colour metaphor to sense/paraphrase;
- omission, if the metaphor is redundant or colour word was unknown/untranslatable;
- mistranslated colour word/colour metaphor (original meaning gets lost in translation).

As colour metaphor translation is certainly more interesting, we hereafter only report on results of colour metaphor translation. Each colour metaphor was analysed separately. Summary of three most characteristic cases of metaphor translation are presented in Table 3.

Metaphor	Rose-coloured glasses	Blue in the face	Yellow-bellied person
Translation strategy	% of usage	% of usage	% of usage
Reproduction of colour metaphor containing colour word or metaphor	94%	69%	0%
Replacement with a metaphor containing no colour word	4%	16%	55%
Converting colour metaphor into sense/paraphrase	2%	11%	11%
Omission of metaphor	0%	2%	16%
Obvious mistranslation	0%	2%	18%
Total	100%	100%	100%

Tab. 3 – Summary of three examples of context-free translation of English colour metaphors into Estonian.

3.1. Rose-coloured glasses

English colour metaphor looking through *rose-coloured glasses* refers to seeing things in a positive light: to see only the pleasant things about a situation and not notice the things that are unpleasant [9]. This phrase is also lexicalised in Estonian with a similar meaning as well as with a similar colour word: *roosad prillid, läbi roosade prillide nägema või vaatama* [10]. This could explain why participants of the study translated the phrase quite similarly using the colour word rose (*roosa* in Estonian). There were no comprehension or translation problems related to this metaphor.

3.2. Blue in the face

Metaphor *blue in the face* refers to a situation where someone is exhausted from anger, strain, or other great effort [11]. In Estonian, there are different colour words used to refer to a similar emotion: blue in the face (näost siniseks in Estonian) and green in the face (roheliseks minema in Estonian) for getting angry [12], also *red in the face* (*näost punane* in Estonian) from anger, strain etc. [13].

Participants of the study also used different colour words. Blue and green were utilised, but white also appeared among the translation equivalents. In cases where metaphor was preserved in translation without a colour word, the most frequently used response was: *not quite like yourself from the face* (*näost ära olema* in Estonian). For paraphrasing the colour metaphor, the participants chose between *vihane* ‘angry’ (*vihane* in Estonian) and *exhausted* (‘*kurnatud või pingutusest üleväsinud*’ in Estonian).

However, what seems to be noteworthy is the case of mistranslation: someone with *visible marks of violence* (‘*vägivallatunnustega*’ in Estonian) that suggests suffering an injury resulting in bruises that are most commonly referred to with a colour word blue. This allows us to conclude that other associations might emerge during translating colour metaphors when there is no supporting context.

3.3. Yellow-bellied person

In English, *to be yellow-bellied* refers to being cowardly or easily scared. If you are yellow-bellied, you are not brave [14]. In Estonian, however, there is no reference to a similar metaphor with a colour word yellow. Neither is yellow associated with cowardliness or any other negative associations. Therefore, it is not surprising, that the participants did not reproduce the metaphor in target language with a colour word. The most frequently used translation strategy was to replace colour metaphor with a metaphor without a colour word – *cowardly* (‘*argpüks*’ in Estonian). Participants who preferred to paraphrase the meaning of the metaphor into Estonian translated it as someone *who is better safe than sorry* (‘*keegi, kes pigem kardab kui kahetseb*’ in Estonian).

During retrospective interviews, several participants noted that this was a novel metaphor, which they encountered for the first time. Therefore, they faced comprehension difficulties and had to look up for the meaning in order to be confident about the translation. Participants who did not know the meaning of the metaphor and decided not to check it up from a dictionary, were misguided. This resulted in obvious mistranslation – *yellow-bellied* became *someone with a big, fat and yellow belly* (‘*suure kollase rasvase kõhuga inimene*’ in Estonian). In one of the cases of obvious mistranslation opposite meaning to the original was used in target language – *brave like a wolf* (‘*julge hundi rind on rasvane*’ in Estonian).

This metaphor was among the ones most frequently being omitted in the questionnaire. Retrospective interviews revealed that the reason lies in the fact that it was a novel metaphor. Participants who looked up for the meaning found that some sources referred to being yellow-bellied to being originally from Lincolnshire [15]. As this was too confusing, they decided to leave the phrase untranslated in order to avoid making a mistake. Most participants emphasised that supporting context would have helped them to translate both single colour terms as well as colour metaphors.

4. Conclusions

Colour terms are relatively small units from a rather closed semantic field and translating them should be easy and straightforward, but when people were asked to translate colour terms as well as metaphors containing colour words, colour terms caused equally as much confusion as any other words or types of text. We noticed that experienced translators offered more creative translations than novices. Gender differences could not be discerned because the male sample was too small, but intriguingly, age, education and knowledge of foreign languages had no comparable impact on the translation outcome. Translating can also trigger semantic priming – *rose-coloured glasses* in English had been translated as ‘(i.e. rose)-coloured glasses’, or *true colours* can trigger word-to-word translation *through colours* (‘*läbi värvide*’ in Estonian). In a context-free task where participants were only presented to words or single sentences without any additional context, obvious mistranslation occurred twice as often as in context-based tasks which we report elsewhere. The study emphasised that translation of colour terms and colour metaphors can often result in a fallacy being produced, because of the linguistic and cultural differences between languages. In addition to cultural aspects, modern metaphor theory emphasises the usefulness of the context [16], [17].

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9. Colour and Education

The meaning of colors in two different child development stages

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1. Introduzione

Con Through their lives, human beings learn how to relate and communicate in different ways and, through contact with others, they understand and use language and its diverse objectivations. Such objectivations are comprised of signs, symbols and meanings [1]

People communicate in two ways with verbal and nonverbal communication. The non-verbal transmission occupies 60-90% of all the communication[2]. Color is part of that non-verbal language by means of its meanings; thus, it is considered a communication element due to the symbolic richness that it conveys in addition to its relationship with other colors and the elements and objects that surround them, and that have been manifested through words or iconic representations in textiles, paints, movies, tv and electronic media, among others. Semiotics will guide us in the study of the signs and symbols which integrate a message; this through the analysis of its effects by means of the different meanings, interpretations, and associations attributed to them, as well as the establishment of a relationship between them and the cultural processes.

However, as is well known, the polysemy of colors increases accordingly to the temporality of the distinct societies; this implies a more systematic study of the meanings in certain cultures and the different stages of human development. Based on this premise and with the purpose of analyzing the meanings of the colors and its relationship to human development through the child cognitive development, we departed from Piaget and his followers' theory. He describes four stages where the children, depending on their age, interpret their surroundings and constitutes their symbolic world, whose function is "to evoke objects or situations not currently perceived using signs and symbols."

Piaget, in his book "Play, Dreams and Imitation in Childhood" (1959) mentions that "*Language acquisition is subject to the exercise of the function based on the development of imitation and play as well as on the generation of verbal mechanisms*" and is obviously subordinated to the stage of the children.

Any object can become a reference symbol if a person stipulates something must be interpreted in some way in terms of the entity it represents in order for it to acquire a symbolic nature.

According to Peralta, Salsa (2003) and Salsa (2004) based on Vygotsky, children enrich their symbolic universe through the most experienced members of their culture and their participation in their cultural group. For this reason and according to the theoretical model of De Loache [4,5] is necessary for the children to have a reference that could be the similarity or based on the physical aspect denominated the and that us that the bigger the , the the mental of the first is done and the promotes the of the

experience of diverse in particular contexts [6,7] so the core of the symbol-referent relationship is intrinsically abstract.
For this reason, it is complex to analyze the symbolic associations of color, since information arrives visually or socially through social media, familiar comments or by the presence of color in the entire cultural environment, which generates a recognition code with particular characteristics that could be ciphered by specific social groups.
Generally, color is not present alone by itself, i.e., it is always accompanied by a natural phenomenon or an object. It has been stated that colors are in an iconic language; however, Ortiz:[12] found it is not indispensable that a color is attached to an object to have a specific meaning, furthermore, it doesn't even have to have the color itself since it could be substituted by the world that represents the color itself and, in such a way, generate a series of meanings for colors which could become permanent. However, when personal meanings appear, these could be easily ciphered by analyzing their context due to a cognitive recognition process.
In this work, study populations were (according to Piaget) in the second and third stages. The first one is the so-called preoperational stage and is characterized by an increase in the use of the complexity of the symbols and the use of the symbolic game and it is not limited by the immediate physical world, although children sometimes tend to confuse the mental, physical and social reality which generates animism and begins to distinguish the tangible reality from the mental reality without leaving the magical thought as an explanation of things. They can also turn to drawing (and color) to depict objects and facts.
The third stage is the concrete operational stage (7-12 years) where the thoughts are less intuitive and self-centered, thus becoming more logical. At the end of this stage, the thoughts begin to become reversible, flexible and much more complex; children perceive more than one dimension of the objects (multidimensionality) and they rely on logic to find differences between them; they begin to look for causal relationships between events.
Within the integral cognitive development, color is not just an element of communication for children, but a means that allows them to express their emotions, life situations, and that helps them to understand their surroundings by means of the interactions with color and their meanings, whether they are linked to natural phenomena [9] or are derived from the socio-cultural context itself, which constantly increases their vast diversity of meanings. Ortiz:[12].
Thus, the relationship between color and its meanings is individual and subjective and sometimes it responds as an element of adaptation or as a way to demonstrate emotions. In general, the color-emotion relationship is based on the classification of warm and cold colors (based on the wavelength) and emotions are added based on them. For this reason warm colors are generally associated with the sun, heat, and fire and are linked to the energy, life and strength, among others; while colors considered cold (blue, green, purple and violet) are associated with freshness, water, depth, ice, and distance among others. However, it should be remembered that these associations may change according to the relationship between a color and the other colors.

2. Methodology

This research is based on the fact that children, from an early age, associate colors with a range of meanings that vary with age. Accordingly, we studied groups at different stages of development, according to Piaget. The first stage is called preoperational and it is characterized by concrete thinking with increased use of the complexity of the symbols. The third stage is that of concrete operations (7-12 years) where thoughts are based on logic and children begin to look for causal relationships between events.

Method

We carried out the research employing a mixed method that allows the comparison of two independent samples and the analysis of categories. It was a descriptive, cross-sectional, comparative study based on the following research questions:
Are there differences in the meaning of colors between children in the preoperational stage and the concrete operational stage?
Are there differences in the abstract and concrete meanings of the colors between children in the preoperational stage and the concrete operational stage?

General Objetive

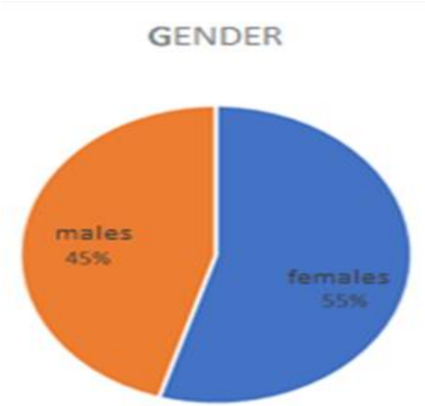
To know the similarities or differences between the samples studied, between the concrete or abstract meanings.

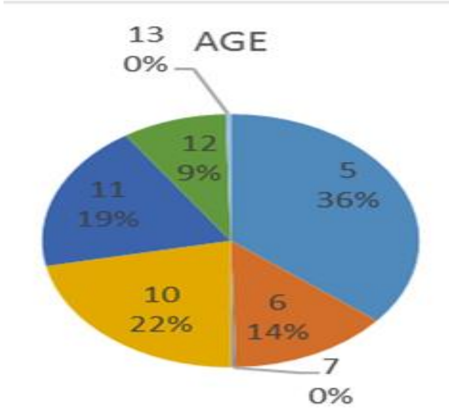
Instrument

The instrument contained the name of nine colors (red, pink, orange, yellow, green, blue, purple, black and white) to which one or more meanings had to be added, along with an identification card with the following information: sex, age, grade level.

Sample

In this study, we analyzed the answers of girls and boys from two different age groups; the first one included preschool children aged 4-6 in the preoperational development stage. The second one included elementary school girls and boys aged 10-12.
The sample consisted of 117 children in the first group and 117 in the second group. The first group consisted of children aged 5-6 years who were in the third grade of preschool. The second one consisted of children aged 10-12 years who were in the fifth and sixth grades of elementary school. The sample consists of 128 women and 106 men. The median age for the preschool group was 5 years old and the median age of the elementary school group was 11 years old.





Statistical Analysis

We performed a descriptive statistical analysis through the SPSS program, with double-entry tables and a chi-square analysis.

Procedure

The following procedure was carried out in order to know the meanings of the colors mentioned in two different age groups of two different school levels:

- A research on the meanings of nine different colors in both groups.
- The meanings were categorized regardless of the number of mentions.
- These categories were classified into abstract and concrete concepts.
- The obtained data were analyzed.
- The chromatic patterns with the original meanings of the colors were searched.

Results and data analysis

A first analysis was carried out to see if all the children responded to the questionnaire. We found that in the first group 10-17% of the children did not give one or more meanings in any of the nine colors; while in the second group, only between 0.9-6.8% of the children did not answer. This difference was attributed to age. The youngest interviewees have less vocabulary since, as Peralta and Salsa (2003) and Salsa (2004) based on Vygotsky mention children enrich their symbolic universe through the most experienced members of their culture and their participation in cultural groups and is obviously influenced by age.

Although children were asked to give three meanings per color, most of the children in the first group (75%) gave only one meaning unlike the other group in which it was more than 90%. The explanation for this was that as children get older, they adopt the meanings prevailing in their social context and they form the basis of a chromatic language.

As shown in TABLE 1, the number of answers found was very similar for each color. Green was found to be the color with the highest number of responses in the youngest group of children; while red was found to have the highest number of responses in the second group. In both groups the color that had the fewest frequencies was purple.

Table 1. Total frequencies per color in both groups.

	Preschool		Elementary school	
	F	%	F	%
Red	124	106.0	124	106.0
Pink	123	105.1	116	99.1
Blue	124	106.0	117	100.0
Green	130	111.1	112	95.7
White	124	106.0	110	94.0
Yellow	125	106.8	114	97.4
Black	115	98.3	114	97.4
Purple	113	96.6	110	94.0
Orange	122	104.3	114	97.4

After the analysis of the meanings, 32 categories were generated for both groups in order to reduce the meanings and to be able to categorize them into abstract and concrete (see table 2), where eight categories constituted the abstract concepts and 24 the concrete ones.

Table 2. Categories of integration of meanings into abstract and concrete meanings for both groups:

ABSTRACT	CONCRETE
Abstraction	Water
Action	Food
Negative behavior	Animals
Positive behavior	House
Traditional celebrations	Sky
Death	Weather
Negative feelings	Color
Positive feelings	Construction
	Sports
	School
	Holidays
	Flowers
	Fruit
	Fire
	Light
	Night
	Objects
	Homeland
	People
	Plants
	Clothes
	Earth
	Transportation
	Universe

Regarding the number of meanings given in total by the groups, we found that the first group mentioned 294 meanings, 25 (8.5%) of which were abstract concepts. The second group mentioned 290 different meanings, 154 (53.1%) of which were abstract concepts.

Categories: Abstract and Concrete by Age and Color

Regarding the concrete and abstract meanings, as shown in Table 3, in the first group there were mainly concrete meanings (above 85%) i.e., they were linked to a particular object. In the second group, abstract meanings (meanings that do not evoke a specific object) increased and represented more than 60% of the total mentioned. The difference is in the concrete meanings (see table 3). Because of these differences, a decision was made to perform a chi-square analysis of the data (table 4).

Table 3. Categories: abstract and concrete by grade level and color

Color	Concepts	Preschool			Elementary school		
		F	%	MEANINGS	F	%	MEANINGS
Red	Concrete	119	101.7	59 meanings 5 abstract	45	38.5	21 meanings, 14 abstract
	Abstract	5	4.3		78	66.7	
Pink	Concrete	115	98.3	67 meanings, 4 abstract	43	36.8	40 meanings, 23 abstract
	Abstract	6	5.1		73	62.4	
Blue	Concrete	111	94.9	73 meanings, 7 abstract	72	61.5	42 meanings, 31 abstract
	Abstract	13	11.1		45	38.5	
White	Concrete	119	101.7	69 meanings, 4 abstract	33	28.2	49 meanings, 29 abstract
	Abstract	5	4.3		77	65.8	
Black	Concrete	109	93.2	69 meanings, 6 abstract	34	29.1	44 meanings, 27 abstract
	Abstract	6	5.1		77	65.8	
Orange	Concrete	108	92.3	66 meanings, 7 abstract	58	49.6	55 meanings, 24 abstract
	Abstract	14	12.0		54	46.2	
Yellow	Concrete	119	101.7	70 meanings, 4 abstract	60	51.3	48 meanings, 26 abstract
	Abstract	4	3.4		52	44.4	
Green	Concrete	125	106.8	57 meanings, 2 abstract	76	65.0	46 meanings, 27 abstract
	Abstract	4	3.4		36	30.8	
Purple	Concrete	105	89.7	69 meanings, 7 abstract	34	29.1	71 meanings, 45 abstract
	Abstract	8	6.8		71	60.7	

Table 4. Chi squared, grade level vs. Abstract/concrete concepts

	Pearson Chi-square (grade level abstract/concrete concepts)		
	Value	DF	(Bilateral) asymptotic significance
Red	51.861[a]	1	.000
Pink	76.321[a]	1	.000
Orange	36.656[a]	1	.000
Yellow	51.861[a]	1	.000
Green	28.671[a]	1	.000
Blue	23.478[a]	1	.000
Purple	78.527[a]	1	.000
White	96.142[a]	1	.000
Black	94.990[a]	1	.000

Table 4 shows that there are significant differences between the abstract and concrete meanings of the colors that were mentioned at different school levels.

An analysis of colors of the abstract/concrete meanings vs. school level categories found that for red, pink, white, black, and purple, preschoolers mentioned a greater number of concrete meanings and elementary school children a greater number of abstract meanings. However, for blue and green colors, both groups mentioned mainly concrete meanings. On the other hand, for the yellow and orange colors, preschoolers mentioned a greater number of concrete meanings, while in the elementary school group there were a similar number of concrete and abstract meanings.

Meanings and colors

Of the diversity of meanings each group mentioned (294 for preschool and 290 for elementary school), each color had a different number of meanings from each group (see Table 5). In table 5 we can see that colors have a considerable number of meanings depending on the group and the color.

In the preschool group, the maximum number of meanings mentioned per color was 73 for blue and the lowest was 57 for green. In the elementary school group, the maximum number of meanings mentioned was 71 for purple, and the lowest was 21 for red. These results showed that the number of meanings decreases with age, with the exception of the color purple, which had an increase of two meanings in the second group in comparison to the first; this may be due to the fact that this color is not commonly found in the social context of infants. In the case of the color red, which had 59 meanings in the first group and only 21 in the second, the reduction in the number of meanings to less than half is striking; this leads us to consider that, as it is a color that is used very often in the social context, the first meaning that comes to mind becomes narrower.

Table 5. Sum of meanings that were mentioned in each group

Color	Preschool		Color	Elementary school	
	# of meanings	Place		# of meanings	Place
Blue	73	1	Purple	71	1
Yellow	70	2	Orange	55	2
White	69	3	White	49	3
Purple	69	3	Yellow	48	4
Black	69	3	Green	46	5
Pink	68	4	Black	44	6
Orange	66	5	Blue	42	7
Red	59	6	Pink	40	8
Green	57	7	Red	21	9

Another analysis was the comparison of meanings in both groups to see if some meanings from an early age remain in spite of the time and if they generate chromatic patterns. For this, a comparison of meanings was made, and we found that, depending on the color, common meanings were mentioned (see Table 6). Almost all the concepts were concrete, except for the joy for the colors orange and purple.

Table 6. Meanings mentioned in both groups

MEANINGS BY COLOR IN BOTH GROUPS								
Red	Pink	Orange	Yellow	Green	Blue	Purple	White	Black
Apple	Flower	Oranges	Sun	Tree	Sky	Grapes	Sheet of paper	Hair
Heart	Girl	Tangerine	Banana	Grass	Water	Flower	Cloud	Darkness
Car	Dress	Joy	Flower	Plant	Boy	Joy	House	Night

Blood	Sadness	Sun	Fire	Flag	Beautiful	Beautiful	Sky	Car
Fire		Fruit	Sunflowers	Pear	Sea		Nothing	Balls
		Plant	Moon					
			Bird					
			Chickens					

These meanings were then analyzed by determining the frequencies reached. In the preschool group, the apple-red, orange(fruit)-orange(color), tree-green, hair-black and leaf-white pairs had a high frequency. In the elementary school group, the pairs with the highest percentages were blood-red, the sun and fruit-orange, water-blue and darkness-black (see table 7).

Table 7. Concepts that are mentioned in both groups but only have a higher percentage in a single group.

		Preschool	Elementary school
Colors	**Concepts**	**%**	**%**
Red	Apple	30.8	
	Blood		29.9
Orange	Oranges	25.6	
	Sun		10.3
	Fruit		17.1
Green	Tree	19.7	
Blue	Water		11.1
Black	Hair	9.4	
	Darkness		17.1
White	Sheet of paper	9.4	

The meanings flower for pink, the sun for yellow, grass for green and sky for blue had a high frequency in both groups, so it can be said that these colors have concepts that do not vary in relation to age, i.e., they are permanent in time, this may be because they are concepts related to nature and children are always surrounded by them (see table 8).

Table 8. Concepts that are most frequently mentioned in both groups

	Preschool	Elementary school
Concepts	**%**	**%**
Flower	13.7	10.3
Sun	21.4	23.9
Grass	14.5	18.8
Sky	12.0	36.8

Considering the concept of chromatic patterns [10] that defines them as “those representations whose purpose is to determine if there is a relationship between the different meanings mentioned for one or several colors or a color that relates to different meanings”, we analyzed the most mentioned meanings for each color. We found the following patterns for each of the groups studied:

PRESCHOOL-LEVEL COLOR PATTERNS

With 4 colors	Flower	Red	Pink	Yellow	Purple
With 2 colors	Sheet of paper	Green	White		
	Cloud	Blue	White		
	Wall	Orange	White		
	Sweater/sweatshirt	Pink	Black		

ELEMENTARY SCHOOL CHROMATIC PATTERNS

With 3 colors	Friendship	Pink	Blue	Purple
	Love	Red	Pink	Purple
	Tranquility	Green	Blue	White
With 2 colors	Joy	Yellow	Orange	
	Sky	Blue	White	
	Anger	Red	Black	
	Flower	Pink	Purple	
	Nature	Pink	Green	
	Hate	Yellow	Black	
	Sun	Orange	Yellow	

It is worth mentioning that in both groups, the meaning "**flower**" was mentioned for the pink and purple colors so it could be considered as a permanent meaning since it is consistent with Ortiz's research [10,11,12].

3. Conclusions

In this research, we found that the children in both groups can associate colors with different meanings, which they modify over time through interaction with others, as mentioned by Berger and Luckmann [1]. This leads them to integrate signs, symbols, and meanings from an early age. However, this integration is aligned with the children's cognitive development, during which, according to Piaget's theories, the symbol is formed in the children and therefore, the language of the colors as a function of the game, the imitation and the children's own development [13] and with the relationship with the most experienced people of their culture and the participation of their cultural group Vygotsky [15,16].
It is important to emphasize that children associated the verbal or written words with a series of meanings without the colors being present, since as mentioned in Ortiz:[12], it is not necessary for a color to be attached to an object in order for it to have a specific meaning, in fact, it does not even have to have the color itself since it can be replaced by the word that represents the color and thus generates a series of meanings of the colors that may become permanent; however, when personal meanings appear, they can be easily deciphered by analyzing the context in which they are found thanks to a process of cognitive recognition. Generally, color is not present alone by itself, i.e., it is always accompanied by a natural phenomenon or an object. It has been stated that the colors are within an iconic language; however, as expected, both groups presented abstract meanings because they were not directly related to a natural phenomenon or a specific object.
Among the primary results, we found that:

• In the first group (preschool), mainly concrete meanings that were linked to a particular object were mentioned. In the second group (elementary school), abstract meanings represented most of the meanings.

• Some basic concrete meanings remain, regardless the cognitive development.

• The chromatic patterns found at the preschool level were lower than those of the elementary school level, but in the first group, a relationship of the meaning "flower" with four colors was found, while in the elementary school group the maximum presence of colors qualifying a meaning was three.

• The chromatic patterns for the preschool level were of concrete meanings, while for the elementary school level, there were the so-called abstract meanings such as friendship, love, tranquility, joy, anger, and hatred.

From the above, it can be concluded that for the research questions: "Are there differences in the meaning of colors between children in the preoperational stage and the concrete operational stage?" and "Are there differences in the abstract and concrete meanings of the colors between children in the preoperational stage and the concrete operational stage?" the answers to both questions were affirmative.

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10. Colour and Communication/ Marketing

Technical Development and Emotional Effect on the Color of the Cinematographic Image

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1. Introduction

The aesthetic effect of color on any artistic work is undeniable; yet; many people may not recognize its psychological and emotional influence despite being one of the important expressive tools that artists can utilize.

Color is distinguished with an advantage known as metaphoric eloquence; artists can load colors with many contents and meanings which they aim to indirectly convey to the audience.

Color symbolism affects all visual arts in general; and cine films in specific; as it has a major role in creating the dramatic idea and emotional mode of a film; as well as specifying and outlining the place and time of it; it can also deeply express the complications of the idea and the psychological aspects of the characters.

Since its beginnings; and for a long time; cinema had remained colorless and confined in using the effects of light and shadow, so image artists struggled to use limited hues of black, grey and white to obtain an aesthetic expressional structure capable of achieving the watching pleasure for the audience.

Many of the well-known directors believe in the emotional effect that color has on audience; and its ability to convey a message that other tools can hardly deliver; this belief inspired them to create many methods to utilize color in their works, from hand coloring [1-pp.2]; as in the movie "The great train robbery, 1903"; to dying a group of scenes with a specific color; by soaking the film strips in chemical pigments; as done in the movie "Intolerance, 1916" to signify the changing eras in the film context.

Fig.1- hand coloring in "The great train robbery,1903"

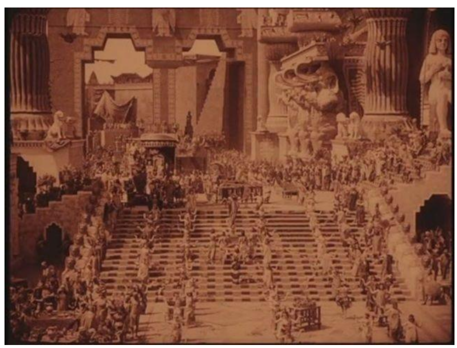

Fig.2- chemical dye "Intolerance, 1916"

Also; the original copy of the American film "The Birth of a Nation"; directed by D.W. Grifth; was dyed with colored materials to indicate the significance of film events; the scene of Atlanta burning was colored in red, while night scenes were colored in blue and the outdoor love scenes in pale yellow [2-pp.47].

Sergei Eisenstein had also realized the importance of color and acknowledged its expressive asset and dramatic influence; so he hand-colored the flag in red in the first version of "Battleship Potemkin, 1925"; which had a major moral effect.

With the evolvement and artistic development of cinema industry; the expressional role of colors has become more affirmed, due to their indications that can vary according to their utilization in the film construction; as well as their connection with events and situations.

2. Methods of color utilization in cinema

The utilization of color in cine art can be specified in the following [3-pp.38-42]:

2.1. Realistic method:

The simplest form of this method is to transcribe colors as they exist; or as we observe them; in real life without any intervention from the filmmakers, this method is used nowadays in dogma cinema and some independent films.

Nonetheless; sometimes the artist might make simple adjustments; by choosing or changing some colors; to create a special type of color, time, place; or even psychological; harmony, but still in a realistic manner.

2.2. Influential method:

In this method; color value is utilized to implicate some familiar significances, such as using warm colors; especially red; to imply certain meanings or emotions like warmness, heat, passion, violence, blood … etc.; while using cool colors; e.g. blue and grey; to express the opposite; i.e. coldness, death, eeriness, isolation or defeat.

The image artist uses many styles to attain or apply these meanings; such as to dye the complete image with one color; or to dominant this color through the formation of the elements of light, décor or accessories.

The most recognized and famous movies usually tend towards the impressionism style; as indicated by Michelangelo Antonioni; "it is essential to interfere in the colored movie to dismiss the regular reality and replace it with the current moment reality" [3-pp.39].

The color Influential method also involves psychological utilization of color to imply the emotional state of the drama characters; Sergei Eisenstein thinks that "the main condition to use color in a movie is that it must have a dramatic indication" [2-pp.47], he also said "color is good when it is necessary, this means that color is good where and when it can most fully express or explain what must be conveyed, said, or elucidated at the given moment of the development of action" [4].

Many of the cinema directors choose colors according to several factors; their culture, their knowledge and experience in using color, their perception of it, how they discuss it with their lighting designer or cinematographer, the show or film itself and its requirements in regards to colors; all these factors may change during the career of each director; thus; they have various influence on their work [5].

3. Color symbolic indication

An artist ensures that the chosen color indirectly affect the film; in other words; that the audience doesn't perceive it as a color, but as an implication that descends in their subconscious and convey the intended emotion; without distracting their attention from the events and characters.

Cinema has benefited from the symbolic indication of colors which correlates with many legacies; as well as social and religious beliefs with all their different cultural contents and various orientations; which are stored in the human mind to be recalled as soon as an individual encounters a symbol and spontaneously interpret it. Therefore; these memorized legacies, beliefs and orientations; which are influenced by the values and ideas that most people in the same culture comprehend; have been known as "ready-made symbols" which; when perfectly invested and utilized; have an expressional energy that can be greatly capitalized on.

The emotional reaction to a specific color and its formations appears to be internationally common, as visual concordance and inconsistency seem to have the same influence; although with different levels; on all humans. Therefore; when an image is repeated in different color schemes, it can express different moods and emotional states according to every change that happens to the image or in the scheme.

Colors have different energies, each color communicates a unique feeling and affects us differently [5], the cine artist can demonstrate characters, their psychological states and their connections with their surroundings through the symbolism of color. The relations created by the contiguity of color spaces, their movement or density amid total context, will create color symbols based on the harmony or conflict of every change that occurs in them [6- pp.22-27].

Artists draw their power from controlling, handling and utilizing their color tools in the best method to attain their visions; they can manipulate meanings, feelings and emotions by simply altering the color schemes.

4. Color psychological indication

The psychological effect of colors on the receiver has been the main subject of many studies that were conducted by examining the relation between the color; that is measured and calculated based on the standard viewer, and the color as actually perceived by the human mind or intellect. These studies have proved the psychological and emotional effect of color on the sentimental sensations and feelings, some colors stimulate happiness, joy and delight; while others induce sadness, sorrow and depression.

Therefore; color in cinema is considered to be one of the image elements that can be artistically altered to indicate the psychological states; whether internal or external; that human beings experience, by generally controlling the dominant color scheme of the film. By using spaces of different colors, the cine artist recalls all cultural beliefs, human heritage and life-acquired experiences embedded in the subconscious; which are linked with these colors; in addition to the artist's personal passions that affect their color choices.

Colors have general implications that most people in the same cultural environment perceive in the same way; studies have proved that color is a clear and effective language that is capable of conveying indications, ideas and meanings. “From a psychological perspective; color in a movie tends to be a subconscious element; as it expresses and creates moods; rather than an intelligent or conscious element, scientists have concluded that while most people try to effectively interpret the pattern schemes; yet they tend to adequately accept color to be an indicator of the atmosphere more than the perceivable elements” [2-pp.48-49].

A color becomes a symbol when linked with a character, creature, place, subject or theme; as visual scenes connect with the viewer’s emotion, also, repeating colors in the same pattern, and then altering them during film context; according to some time- or state-related events; can indicate changes in the character, storyline or subject of the film; “when chosen carefully; a well-placed movie color palette evokes mood and sets the tone for the film” [7].

According to Frederico Fellini, color is the main part of the ideas and concepts presented in a film, because it doesn’t engage in its language only; but in the film’s knot itself, he also sees that color plays an important role in the psychological states indicated in the film; whether confusion, anxiety, fatality, sadness or depression [2-pp.53].

Cinema makers along the history of the industry have always depended on common uses of color that have psychological and emotional effects on the audience; some of which are:[15][16]

Yellow: it is the stimulating color of sunlight, a symbol of wisdom, warmness, power, sunrise, joy, richness and radiance. When used in dark hues, it indicates degeneration, weakness, jealousy, cheating and illness, while light yellow indicates envy, forgery, doubt, treason and madness.

Blue: a cold color that calls for relaxation and comfort, reliefs muscle tension, helps calm rapid pulse or breath and gives the feeling of infinity. It relates to the sky, water, symbolizes fictional happiness; and indicates steadiness, continuity, faithfulness, intelligence, trust, generosity and immortality, although dark blue may indicate superstitious, fear and devastation.

Red: its symbolic indication has been subjected to many interpretations, as it is the most energetic color that stimulates appetite and lust. Red is the color of fire and blood that stirs attention and effectiveness. It indicates warmness, love, anger, excitement, power, violence, ruggedness, danger, killing, hatred, cruelty, hardness, shyness, demolition, vandalism and revolution.

Some people think that red color creates a shock that causes disturbance and tension; while others think that it indicates power, ambition and victory.

Purple: was regarded as a regal symbol for a long time, as it implies delicacy and majesty, mystery, pride, wisdom and spirituality, it symbolizes conspiracy and might slightly suggest sadness.

Green: Eisenstein has linked it with plants and considered it to be a symbol of life and nature, some people conceive it a symbol for fertility, renovation, activeness, contentedness and hope. Green suggests relaxation and trust; it is cool enough to provide comfort; but also warm enough to attract attention and please the eyes.

Orange: symbolizes abundance, heat, warmness, sunset, glowing, fierceness, excitement, happiness, satisfaction and contentedness. Orange has a relaxing effect on some people but causes tension to others.

Black: a symbol for mourning in many countries, it implicates evil, old age, silence, death, grief, invisible acts, darkness, fear, blindness, composure, disasters, ambiguity, horror, deceive and crime, but also sophistication, authority, style.

White: the symbol of purity, chasteness, cleanliness, trust, peace, modesty, weakness, frailty, surrender; it is also the color of mourning in some countries.

Grey: implicates coldness, affableness, submission, gloominess, determination, resolution, composure, poise, senility and sometimes anguish and sorrow. Pure grey is the only color that has no direct psychological properties.

Brown: symbolizes autumn, reaping, abundance, satisfaction, sorrow, depression, warmth, nature, and earthiness

Violet: symbolizes royalty life, luxury, authenticity, calming and sedating color. It lifts-up the spirit, quietness, frailty, weakness, sorrow, love and compassion

On the other hand; and despite all studies and theories; the utilization of color in cinema is not dogmatic, although cine artists depend on color implications, yet they aren't confined in their limits. There are no specific or obligatory rules here; the artist decides the color hue, value, distribution and contrast with its surroundings according to his perception of the color theory; and these choices specifies the reaction of the audience.

A color can be used in an image individually, to implicate a deeper meaning or a specific psychological state; that the watcher is drifted towards; or to frame the scene with a specific emotion conveyed to the viewer through this color. Nonetheless, using a color scheme has a bigger effect in achieving a realistic mood; whether the colors were harmonious and coordinated, or contrast with each other; in order to obtain a solid film language that sustain the communication process, thus; it can be said that "color theory norms should be understood by filmmakers, but never seen as a limitation" [7].

Hue, value and saturation are the main elements that specify the color; each of them plays a part in delivering the appropriate feeling, and altering any of them will subsequently change the film's atmosphere and style. Nonetheless; controlling or manipulating the color balance or disturbance majorly affects the mood and the ability of color to deliver the feeling.

Every director has his/her own vision in regards to the harmony, consistency and concordance of the chosen colors with each other; this obligates to study color theories, in order to recognize the colors that are harmonious with each other and the colors that are not.

For example; in his film "Moonrise Kingdom, 2012", director Wesley Wales Anderson used the colors yellow, brown and green in a harmonious style to avoid any confliction or contrariness in the color pattern, in order for the image to be exciting and comfortable to the eye, and to give the film a nostalgic quality.

Fig.3- Moonrise Kingdom, 2012

On the contrary; Jean-Pierre Jeunet, director of "Amelie, 2001", has used a complementary color system, in which every color in the scene endorses another color; whether green, red, blue, yellow or purple. Using balanced colors in the image helps to clearly deliver the feeling to the watcher; and set them in the appropriate mood.

Fig.4- color scheme in "Amelie, 2001"

Color balance can also be used to set the audience in the mood to accept the melancholy of a movie; as done by Francis Ford Coppola in his film "Apocalypse Now, 1979", in which he used black and yellow to imply the suffocating atmosphere of the film, and used orange to color dust to implicate the large amounts of poison in the air.

Fig.5- "Apocalypse Now, 1979"

While director Jean-Luc Godard applied the theories of color imbalance in his film "Pierrot le fou, 1965"; he used a various number of colors in every scene; but not in a random style; as he appropriately formed these colors to convey a message that the characters are impartial to all colors and patterns, which allowed the director to freely express each scene as he pleases [8].

Fig.6- “Pierrot le fou, 1965”

5. Using color in the cinematic image

Color is used in cinema in four common styles; which are [7][9][14]

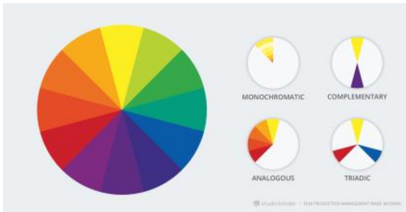

Fig.7. four common color styles in cinema

5.1. Monochromatic color scheme

This style uses one color that shadows all scenes, to acquire the harmony required in the movie and to express the mood of the character.

Fig.8. Examples of the monochromatic color scheme

5.2. Complementary color scheme

The colors in this style vary between the hues of two complementary colors in each scene; e.g. orange and green-blue, or red and green; in order to create a high contrast that causes tension and to signify the internal or external struggle of the character; or to make the image look more alive.

One of the color connections that deeply express struggle; whether internal or external; is the combination between orange and green-blue and their hues, so even if the struggle is internal, the cine artist can express it with color reflections on the external environment surrounding the character.

Color hue, density and space specify the mood and emotional feeling required in the scene, the contrast in complementary colors doesn’t have to be apparent or obvious; density, brightness and hue of the color can be relatively controlled to achieve the required feeling.

Fig.9. Examples of the complementary color scheme

- <u>Split complementary color scheme</u>: instead of using a complementary color, its two adjacent colors on the color wheel are used; for example; instead of using red; as a complementary color for green; it can be substituted with orange and purple, this style decreases the tension created by using red with green.

- <u>Tetradic color scheme</u>: instead of using two complementary colors, the adjacent two colors of each complementary on the color wheel are used in this scheme, providing different, harmonious and balanced color variations, usually with one dominant color.

5.3. Analogous color scheme

This color theme is created by using adjacent colors on the color wheel; contrary to the contrast, tension and conflict caused by using complementary colors; adjacent colors reflects a mood of harmony, consistency and calmness in a scene, whether they were cold or warm colors.

Warm colors; such as red, orange, yellow and brown; can be used to imply warm feelings, while cool colors; such as blue or grey; express coldness, isolation and fear. The meaning or emotion of the scene vary according to the density of colors, a dominant color can be used with another color or two to confirm the intended meaning.

Fig.10. Example of the analogous color scheme

5.4. Triadic color scheme

In this scheme, three colors; that form an even triangle on the color wheel; are used, one of these colors is dominant, while the other two confirm the feeling of contradiction.

This color scheme is the least used in the cinematic image, but despite its difficulty and rarity, it provides a feeling of vitality and liveliness to the image; even if the colors are not condensed; to reflect the contrasting mood and the psychological state related with it.

Fig.11. Example of the triadic color scheme

6. Discordant color scheme

Which is using a color that contrasts with the rest of the colors of a scene; in an obvious, clear and intentional method; so it would be the most apparent color in this scene. This stepping away from the balanced color palette of the film aims to concentrate attention and draw it to the character, detail, moment or place of a specific scene.

Fig.12. Example of using discordant color in the movie

7. Color Script

During the preparation of any film, a color scheme is chosen according to the scenario, costumes, décor, lighting and the dominant colors of all film elements, to create the main psychological and emotional mood and the general atmosphere of the film.

The chosen color palette and the accuracy in colors utilization help the director obtain the emotional aspect of the film and prepare the audience to unconsciously respond to it; as the mood and feeling created by the color pattern and scheme escort the audience; from the beginning to the end of the film.

In Ridley Scott's "Gladiator"; for instance; deep black and dark crimson red were used to reflect the dominant atmosphere of brutality and blood desecration; while ash brown hues were used to confirm the time of the movie and transfer the audience to the Roman era.

Fig.13. dominant atmosphere by using deep black and dark crimson red in"Gladiator"

Fig.14. lively and spirited colors in "Toy Story"

While on the contrary, director John Lasseter confirmed the sense of innocence, childhood and sweet memories by using lively and spirited colors in his film "Toy Story".

8.Technical development and color

The fast and consequent development in the techniques of film production, which started in applying the digital technology in the post-production period for editing, color correction and cinematic tricks, until the transformation of the system completely to the digital system has provided a wide range of artistic possibilities and choices that enable filmmakers to control and manipulate the image, its quality and final chromatic appearance.

Due to restoration purposes, "Snow White and the Seven Dwarfs" was altered and manipulated and then recorded back in 1993; making it the first film to be fully scanned to digital files. While in 2000, the film "O Brother; Where Art Thou?"; written, produced and directed by Joel and Ethan Coen; was the first full feature film to undergo the digital intermediate process [1-pp.4].

The superiority of digital technology was proven by the possibilities and capabilities it has provided to the cine artists, which have had a direct impact on the form and the quality of the cine image itself [10]. The digital technology has cleared the way to the artist to manipulate all elements that form the image; including color, contrast, brightness … etc.; by controlling the indication numbers of these elements, in a process that is known today as "image digital manipulation". This couldn't be achieved in traditional cinema films, where images were formed by the chemical reaction to light that occurs during filming according to specific circumstances; or during the chemical reaction during picture development; where the visual features of the picture can't be altered after its development and reactions affixation.

The modern developments of cinematic cameras; such the Arri Alexa, Sony F65 and Red Epic; enabled filming using RAW modes system, which captures images in an incomplete state to allow the artist to manipulate colors as they choose. However; these advanced techniques require employing more color specialists; who have experienced in the science of color, color management and digital workflows [1-pp.4].

By using the digital system; as well as programs and equipment that control and enhance the quality of the cinematic image with all its elements; artists can interfere to solve exposure problems and adjust the exposure lighting level, sharpness, color correction and other processes of post-production. In addition to changing and altering the features and elements of the cinematic image and re-form it artistically and qualitatively to achieve a dramatic depth. Some programs also operate during real-time filming, they receive the digital output signal of the digital cine camera; and color code it by color management systems; to create color-coded digital files ready to be worked on them in the post-production stage.

These digital programs and equipment have granted much potential for color correction and color appearance in cinematic films, some of which are: [11-pp.9-11]

8.1. Multi-layer color correction; This system provides many possibilities to work on the cinematic image that was never available in the traditional chemical lab system. It dissolves image components into three basic color layers; so that each layer contains one of the basic three colors; using the RGB 4:4:4 systems with color depth up to 32 Bit, then each layer is color graded separately, in order for the colorist to control the hue and density of each color; as well as adjusting lighting contrast; in any part of the cadre through wide dynamic range. It also allows the colorist and the editor to compare between the original film image and the color graded digital image; through two adjacent monitors; to detect the color differences between the two images and process them.

8.2 Total control of color grading; allows conducting more than one color correction with no impact on the image quality, even with different color systems.

8.3. It allows visual modification and color alteration for specific areas in the image; without affecting the remainder of it, which was not available in the chemical lab system that only allowed alteration on the whole cadre.

8.4. It allows conducting a continuous color correction on each shot separately; as well as performing color comparison and visual calibration between the shots of each scene.

8.5 The ability to apply and interchange; the basic tools of primary and secondary color corrections, without affecting the value of the original cinematic image (RAW).

8.5.1. Primary color correction: manages the color density curves of RGB color channels over the whole frame. It affects the entire image with the advantage of individual red, green and blue controls; as well as luminance controls for shadow, mid-tone and highlight areas of the image.

8.5.2. Secondary color correction: separates a specific range of hue, saturation and luminous values to be altered within this range only. It allows grading secondary colors, with a minimum effect on the rest of the color spectrum [12-pp.561]. Secondary color correction is defined by hue, saturation and/or brightness; its graph isolations are defined by "Power Windows" and effects such as Gaussian blur (also known as Gaussian smoothing) [13].

8.6. Enables working in real time.

8.7. The ability to change the color appearance in specific areas of the image without affecting its remainder.

8.8. Controlling the Gama values to set the contrast values.

8.9. All color correction programs are equipped with filters and visual effects ready to be directly applied to the digital cinematic image.

8.10. Managing any type of digital cinematic camera output files with any quality.

9. Quality control softwares

The digital systems for color correction vary according to the different softwares specialized in color correction; each of them has different and distinguished tools that allow artists to control the quality elements of the cinematic image; these specialized softwares include:

9.1. Adobe SpeedGrade software

A complete digital application specialized in color correction; it includes the main standard tools used in color correction processes, which allows the director of photography to apply the required color adjustments to the values of the produced image. It provides the ability to conduct primary and secondary color corrections, integrate and re-arrange visual effects and color corrections for each layer of the digital cinematic image separately.

9.2. Autodesk Lustre software

One of the color correction programs that are equipped with integrated tools; it is compatible with most output digital files of modern digital cinematic cameras. This program is used with a digital intermediate DI system, as it provides the possibility to conduct all primary and secondary color corrections processes on all images; whether cinematic, video or stereoscopic.

9.3. Black Magic Davinci Resolve software

A production of "Black Magic company"; manufactures of digital cinematic cameras; it is an advanced color correction program that is easy to use with portable color correction equipment during the filming process. It has all the common features of other color correction programs, but is advantaged with the capability to manage high dynamic range HDR cine images and display them in real time with a high bit depth; up to 16 bit. It also manages the color void of the ACES digital system, codes the information and colors of digital cine image in a higher quality and dynamic range, and controls noise level [12-pp.463-464].

Conclusions:

- Digital color grading provides a wide range of image visual adjustments that were never possible with the traditional laboratory processing of images.

- Although it is essential to study color theories as a first step, yet; choosing the color theme of a film is totally up to its makers, as it is one of their important tools to communicate with the audience and influence them.

- The digital programs and equipment specialized in controlling the quality of the cinematic image have provided unlimited possibilities and opened wider horizons for the image artists to creatively use color.

- Digital manipulation has enabled the cine artist to control all the elements that construct the image; including color, contrast, brightness and all other formation elements; by controlling the function numbers of them, to be able to change the color scheme of the film in accordance to their vision.

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