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

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# Table of Contents

Editorial	5
<i>Maurizio Rossi</i>	
The Colored Chemistry	7
<i>David Ajò, Giuseppe Elettivo, Federica Fenzi, Stella Nunziante Cesaro, Sabrina Tegani</i>	
DOI: 10.23738/CCSJ.110201	
The colours of the ancient Greek architecture	14
<i>Rossana Netti</i>	
DOI: 10.23738/CCSJ.110202	
Primary colors as a source of possible misconceptions: an insight into teaching and learning about color	25
<i>Berta Martini, Monica Tombolato, Rossella D'Ugo</i>	
DOI: 10.23738/CCSJ.110203	
Chromatic values in Pablo Picasso's early work: a comparison of hues in "Science and Charity" (1897) and its three oil sketches	34
<i>Marcello Picollo, Costanza Cucci, Lorenzo Stefani, Reyes Jiménez-Garnica, Laura Fuster-López, Anna Vila</i>	
DOI: 10.23738/CCSJ.110204	
Education about colour: a look at some authors from the 19th and 20th centuries in Italy: Corrado Ricci, Maria Montessori and Giuseppina Pizzigoni	43
<i>Franca Zuccoli</i>	
DOI: 10.23738/CCSJ.110205	
From Dots to Atoms: "Light and Color" Techniques in Fifteenth and Sixteenth Centuries' Painting	49
<i>Carmen Di Meo</i>	
DOI: 10.23738/CCSJ.110206	

Two theories for a model: the “querelle” between Klee and Ostwald <i>Anna Marotta</i> DOI: 10.23738/CCSJ.110207	63
Under the lens of ISLe: Leonardo da Vinci’s “Landscape” drawing analysed by colourimetry <i>Marco Gaiani, Fabrizio Ivan Apollonio</i> DOI: 10.23738/CCSJ.110208	73
A case study on light and colour for monuments and cultural assets <i>Andrea Siniscalco</i> DOI: 10.23738/CCSJ.110209	82
Evaluation of the perceived colour difference under different lighting for museum applications <i>Alice Plutino, Laura Grechi, Alessandro Rizzi</i> DOI: 10.23738/CCSJ.110210	90
<b>Column</b>	
REVIEW: Nature & Colour - New perspectives on dyeing <i>Renata Pompas</i>	98



# Editorial

Dear Readers, with vol 11 n. 2 we close a six-year cycle and go on for a future of consolidation of our journal in the next year. As announced, the journal web management is now available online via the Open Journal System and DOI database has been updated accordingly, given that the old Joomla site has been discontinued and the URLs of all the previously published papers have been changed. This will allow a better indexing of the published articles and will guarantee the compatibility with Open Archives Initiative Protocol for Metadata Harvesting (OAI-PMH).

Since 2014 we have published 11 volumes for a total of 12 issues, adopting from 2019 the new numbering which publishes one volume per year with two or more issues for each year. Since 2015 we have applied the double blind peer review and since 2016 we have applied the Digital Object Identifier System. This has been possible thanks to the voluntary support of the members of the "Associazione Italiana Colore" who work in the editorial committee, thanks to the members of the editorial board, thanks to the deputy editor Alessandro Rizzi and the President of our association Marcello Picollo who, from the beginning of his mandate, has guaranteed support to the CCSJ. A special thanks goes to Filippo Cherubini of IFAC-CNR who oversaw the migration of our archive to the Open Journal System, to Veronica Marchiafava, the secretary of our association, for the management of DOI database and to Andrea Sinicalco, the vice-president of our association, for the graphic support for the new layout. After six years of publishing of the CCSJ it is also useful to recall the importance of the concept of double open access under which our journal is managed and published: the journal is completely free for both readers and authors. Since 2019 we have also had the significant support of the Associate editors and from this issue we also have a new entry, Agata Kwiatkowska-Lubańska of the Academy of Fine Arts of Kraków (Poland), who will support the peer review process of the papers in the area of Color and Design: furniture, design, fashion, textiles, cosmetics, food design, museography.

The peculiarity of our journal, also written in the statute of our publisher, the Associazione Italiana Colore, is to collect papers on color and related areas in a multidisciplinary way. This basically means that in our peer review process we could have papers ranging from the science of colorimetry to the culture of color in the history of art. Moreover, these papers have very different styles and ways of writing, as diverse is the group of the peer reviewers that constitutes our editorial board.

This *multidisciplinarity* is a richness for the mind, for color science and for color culture, and I will not get tired of repeating it to all those who collaborate in the journal or at the Conferenza del Colore, and specially to those few people who tend cyclically and obstinately to forget it.

*December, 2019*  
*The Editor-in-Chief*  
*Maurizio Rossi*  
*Full professor of Lighting Design and Design Methods*  
*Politecnico di Milano*

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# The Colored Chemistry

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## ABSTRACT

We discuss here materials used in the fabrication of works of art and handicrafts, among them pigments and dyes, gemstones and jewels. Attention is paid to their natural or synthetic origin and possible treatments. Methods of characterization are important not only for historical and restoration purposes and the reproduction of ancient processes, but also for the purposes of new productions. In particular, in the fields of the Effective Microorganisms and metal surfaces coloration, some goals have been reached in this direction due to convergence of different education and research experience of the authors.

**KEYWORDS** Chemistry, Restoration, Gemology, Colored metals, Synthetic materials, Treated materials, Effective Microorganisms

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## 1. Introduction

The cultural association SMATCH (Scientific Methodologies applied to Cultural Heritage) has been created with the purpose of understanding cultural heritage and critically study methods adopted to know and protect it. A science which was always engaged in the sector of "beautiful" is chemistry: in this field we do not make separations between synthetic and analytical chemistry, nor between organic and inorganic: distinction born from a prejudice denied since the indigo industrial synthesis (marketed by BASF, 1897). The material used for the "beautiful" (but the saffron is also used for the "good"...), such as gemstones or in general ornamental objects are made of natural raw materials, subjected, more often than people think, to chemical treatments. A special case is the diaspore (yellow gemological variety: zultanite) which shows (Haüy 1801) how a heat treatment (even at not very high temperature) could unpredictably produce a synthesis. But intentional synthetic processes and treatments are now very common. We will describe in the present paper some of our research activities presenting cultural and productive interest.

## 2. Pigments and dyes

We cite here only a few cases, some of them regarding materials used as pigments in wall painting and not only. The synthesis modalities of such materials are investigated, among the others, for restoration: the advantage for a chemist in fact consists in the possibility of having, obviously not in all cases, items available to compare with the materials of the artifact.

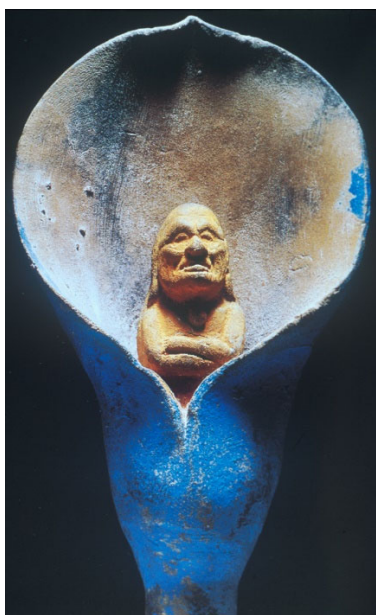


Fig. 1. Maya flower, Jaina (México). Photo courtesy of Giacomo Chiari.

In Europe, in the fabrics dyeing, both natural (in particular extracted from "indigofera tinctoria") and synthetic indigo are employed. On the other hand, in the wall and other surfaces painting (Figure 1), in pre-Columbian times, but also later, we find the Maya blue, a composite material (indigo-palygorskite clay) of exceptional stability. The knowledge of nature and history of this material (Reyes-Valerio 1993, Chiari et al. 1999, Ajò et al. 2000, Berke 2007, Sánchez del Rio et al. 2011) is mostly due to the chemist (but also art historian and microbiologist!), Constantino Reyes-Valerio.

An ancient case of treatment is that of the odontolite, imitation of turquoise, obtained from fossil tusks of mastodon (Reiche et al. 2000) by modification of the oxidation state of manganese.



Fig. 2. Sumerian seal.

The lapis lazuli is very precious because (according to the gemological criteria) "beautiful, rare and durable". On the other hand, Sumerians produced seals (Figure 2) able of transferring with their own mark the magical properties of the stone (Ajò et al. 1996). Since then it was used in jewelry production and as precious pigment to paint the sky, the Madonna mantle and little else (Aula et al. 1997): as a matter of fact, since ancient times the use of beautiful materials, for personal or collective purposes, can have spiritual implications. The production of synthetic ultramarine (analogous of lapis lazuli) was known more than two centuries ago (Plester 1966, Berke 2007).

Egyptian blue, a synthetic silicate of calcium and copper (Pozza et al. 2000, Berke 2007, Dyer and Sotiropoulou 2017) was used in ancient times in Egypt and later also in Italy (Colosi and Prestileo 2017, Bonifazi et al. 2017) in order to imitate copper minerals such as turquoise or azurite: the latter one, in particular, was subject to alterations in the wall paintings. Its production dates back to the I Dynasty (about 3100 B.C.) and originates from the pre-dynastic Egyptian and Asian culture. Initially the blue glassy material (frit) was used as a glaze, and subsequently it was used also as a pigment (Forbes 1955, Riederer 1997). The later use became frequent or exclusive since the V Dynasty (2494-2345 B.C.), for decoration of both organic and inorganic materials. In the Egyptian Middle Kingdom (2133-1786 B.C.) a further extension in its use is witnessed, mainly for decoration of tombs in which wall paintings of exceptional extension were made.

Marcus Vitruvius Pollio (Galvani, 1758) and Pliny the Elder (Plinius Secundus, 1873) inform us that the blue color (caeruleum), was introduced by Vestorius in Pozzuoli, in order to produce and sell it in Italy. The more detailed Roman sources is provided by Vitruvius (first century B.C.), while Pliny presents the diffusion of the Alexandrian blue manufactured in Pozzuoli: he makes indeed know that this color is labelled Vestorianum blue. The production in the Vestorius' factory and the spread of his blue pigment were such as to influence the III Pompeian painting style, originated in the Augustan period. In fact, from the year of Caesar's consulate (59 B.C.), the relationships with Egypt became more intense and frequent until the Age of Claudius (41-54 A.D.). The use of this pigment characterized the 3rd Pompeian style, in which an Egyptian (Vestorianum) blue produced in Pozzuoli was widely used for making blue skies.



Fig. 3. Powdered Egyptian blue functionalized with EM.

We think it appropriate to introduce here the case of white lead, in which a chromatic alteration is frequently observed towards brown, imputable to an oxidative process due to

microorganisms which colonize the wall paintings, producing lead dioxide (plattnerite) (Petushkova and N.N.Lyalokova 1986). These microorganisms are able to oxidize other pigments containing bivalent lead such as massicot and minium. Furthermore, bacteria participate in the conversion of white lead to lead sulphide (black). These and several other evidences make it necessary the study and the experimentation, currently in progress, of antagonistic methods in order to restore and prevent the deterioration of wall paintings. Actually, the antioxidant power of Effective Microorganisms is now recognized and used on a large variety of substrates and in various conditions (Higa 1993, Higa 2018). Theirs reducing power is also exercised on metal ions. Trials are underway on altered pigments, using products based on Effective Microorganisms (EM): in particular, the Egyptian blue has been recently reproduced by EM-Biotech (Figure 3), not only for ornamental purposes but also as a material functionalized by the addition of beneficial microorganisms (EM), for the coating of tanks and swimming pools.

### 3. Precious materials for jewelry

In 1902 (the same times of the indigo BASF) Auguste Verneuil announced the synthesis of a ruby obtained by melting in the flame mixed oxide powders. In one of the laboratories of ICIS (CNR) in Padua, an instrument was designed and used (Figure 4) not very different from that of Verneuil (Maini et al. 2006).

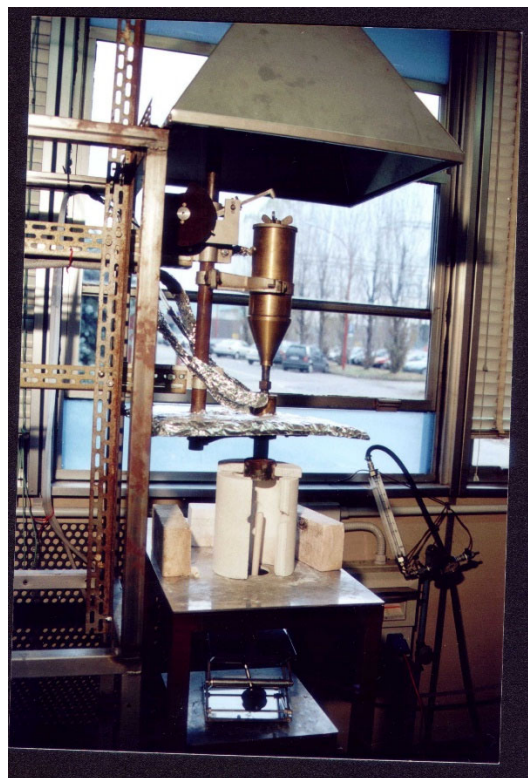


Fig. 4. The Verneuil apparatus of CNR in Padua.



Regardless of the commercial use (Figure 5) of the obtained crystals, not always practicable, a chemist likes to make reference samples, to be compared with an unknown material: "this at least I know how it was done".



Fig. 5. Synthetic sapphire of commercial interest.

Many methods can help the identification and the characterization of a synthetic or treated material starting from elementary analysis not destructive such as X-ray fluorescence (XRF). Spectroscopic techniques, however, are always necessary. In any case, the study is more effective if the person performing the analyses (elementary, structural and spectroscopic) has also experience, at least in some case and to some extent, of syntheses and treatments. In this way it is possible to meet the needs of gemologists and jewelers (Giarola et al. 2012). In fact, in the manufacture of jewelry, for imitation purposes instead of sapphires blue spinels (mixed aluminum and magnesium oxides) are used. Practically, materials very often not existing in nature, are employed which share only a few properties with the imitated material, such as color and gloss, but differ for all remaining properties.

A material different from the more valuable one but showing a similar appearance not necessarily represents imitation on the moral and juridical level. The "Black Prince's Ruby" of the British Crown is actually a red spinel: it is not about an intentional imitation, but an innocent misunderstanding, due to the absence of proper instrumentation. In this regard, it should be stressed that such precious objects are not removable, so it is good to have portable instruments, as the FTIR interferometer used for study the marvelous diamond of Vallerano (Bedini

et al. 2012), which could not leave "Palazzo Massimo alle Terme" (Rome).

Some colors of gems, in particular of brownish diamonds, are considered "ugly" (of negligible commercial value). This reason stimulated the study of methods suitable to change the characteristics of the stones (in particular the color). Often a heat treatment is carried out in order to improve the color of a gem; but a heating procedure can be also effected for diagnostic purpose, producing desirably reversible phenomena; if instead we want to improve the color of a diamond for commercial purposes we desire irreversible changes.

It can also happen that a gem, for the production (not reversible !) of "little flaws, which are singly unperceived" (Shaw 1738) due to a thermal shock, loses apparently its color; but then it recovers it by means of an intentional treatment: in fact these cracks can favor the introduction of a dye, for example cochineal dissolved in alcohol (today we talk about "quench crackling"). We have to meditate on an interlacement of desired and non-desired phenomena.

One of the most important issues of current gemology is the HPHT (High Temperature, High Pressure) treatment of diamonds: high temperature (about 2000 °C), high pressure (about 60.000 atm), launched by General Electric in 1999, capable of transforming brownish diamonds into gems substantially colorless (up to color D).

In order to evaluate "a priori" the effectiveness of this kind of treatment, infrared spectroscopy is employed. In fact, the type I diamonds contain appreciable concentration of nitrogen which makes them less sensitive to physical treatment. On the contrary, this treatment is more effective for type IIa diamonds whose coloration is predominantly associated with dislocations in the crystal lattice: this means that the concentration of nitrogen is negligible. Therefore, IR spectroscopy helps to decide whether or not to apply the process, through an indirect reasoning that is worth reflecting on.

We have already mentioned that a chemist, if he can, creates his own materials: in the case of diamond, treatment for color change is too drastic for an ordinary laboratory; on the other hand in another laboratory of ICIS, some crystal of brownish zoisite (of no commercial interest) were "cooked in foil" at 300°C and atmospheric pressure, obtaining a "pseudo tanzanite" having a pleasant, not natural, blue-violet color.

An operation different from the HPHT treatment, but with some points of contact on the logical and operational level, is the synthesis of the diamond. In 1970 a crystal of potential gemological interest has been produced by General Electric, applying a HPHT technique, in conditions distinct from those of treatments. Catalysts or fluxes such

as metals were used, this procedure suggesting a possible clue to spectroscopists as well as, in some cases, to microscopists. Diamonds produced by HPHT have definitively canceled the distinction between organic and inorganic chemistry, since they were synthesized from biologic compounds such as the peanut butter, then from the "the loved one" by an alternative procedure to burial or ordinary cremation. More recently, diamonds have been presented by the Apollo Diamond of Boston, exhibiting properties (including color and size) of gemological interest, obtained by the Chemical Vapor Deposition (CVD) technique. This method is also used for coatings with thin and hard films, also useful for the protection of some artifacts.



Fig. 6. Synthetic emerald "Malossi".

Some gemstones, such as emeralds (Figure 6), unlike corundums (rubies and sapphires) and diamonds, can grow (from a "seed") at high temperature in aqueous solution by a so-called hydrothermal synthesis (Adamo et al. 2005).

What has been written up to now implies the knowledge of the structure of the materials, in particular of their defects and their impurities; for this purpose it has often been used, among the other techniques, photoluminescence spectroscopy not only for identification purposes but even more for the determination of the oxidation state and coordination of the chromophoric centers.

A very instructive case, in which the distinction between synthetic and natural (same crystalline matrix, same chemical impurities) required the use of different

spectroscopies, is that of blue sapphires. The guiding idea consists in the relatively easiness of reproducing in a laboratory the chemical composition of a sapphire ( $\text{Al}_2\text{O}_3$  with a small concentration of iron and titanium); a bit more difficult is the control of the oxidation state of iron: mainly bivalent in natural corundum (presumably born in oxygen deficiency), trivalent in some synthetics, probably grown up in the air. In general: two materials of the same composition, but born in different natural or laboratory contexts, may have some in common properties, in particular the color, and also density, hardness and refractive index. But they can have different properties as, in this case, the photoluminescence. The fact that, in cases like these, emission and absorption do not go hand in hand can be a problem for imitators but an advantage for gemologists and jewelers (and their customers).



Fig. 7. Strongly oxidized glass.

Even in a sector at first sight "less noble", like that of industrial glass, a tight control of the oxidation state of the iron is fundamental: almost totally oxidized in the glass of Figure 7. This was a subject, together with many others, of the collaboration between ICIS and the Experimental Glass Station (Murano, Venice) (Ajò et al. 1999).

Finally, it may be considered that gems are often set in jewels (whose color effect depends on the combination of stones and metals, or of different gems): the prevalent use of yellow gold, in particular for diamonds, has been gradually overcome by the employment of platinum and white gold, not to mention rhodium-plated metals: yellow gold (or colored) remains the preferred in commerce especially for diamonds that show shades of yellow (for example with a relevant concentration of nitrogen). The combination of the color of the metal with the embedded gemstones is so important that in recent decades new techniques are used to obtain color variations of gold, no longer only due to the different alloys used, but also to the special rhodium treatment (galvanic process).

The rhodium is not only used to make white gold bright and shiny but also to color it (in blue, in black, but the latter not very stable to physical stress). Our present project is to use new metals which after particular treatments produce, by interference, effects till now unthinkable except if obtained through enamelling techniques. The best results so far were obtained with titanium. The study of new surface colors aims to the realization of elegant contrasts between metal and gems, or shades of tone on tone. Besides, some metal colors can today be obtained with PVD (Physical Vapor Deposition) but we are studying also techniques such as DLC (Diamond-like carbon) coatings.

#### 4. Funding

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#### 5. Conflict of Interest

This research holds no conflicts of interest.

#### 6. Acknowledgments

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**David Ajò** - Graduated in Chemistry (University of Rome) and Graduate Gemologist (Gemological Institute of

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**Giuseppe Elettivo** - Graduated in Geology at the University of Calabria (Arcavacata di Rende, CS), specialized in the mineral-petrographic field. Independent gemologist, collaborated with ICIS of CNR (Padua) within a project of the Province of Padua, and taught in the gemology school IRIGEM (Rosà, VI). Expert in estimate and evaluation in jewelry and in the use of precious and non-precious metals.

**Federica Fenzi** - Graduated in Chemistry (University of Padua) she carried out research at CNR (Padua, 2001-2014), with archaeometric studies on glass, ceramics, bronze, pigments, hydraulic binders, and developing syntheses of eco-sustainable materials for industry and restoration. Since 2013 contract professor of chemistry at the Academy of Fine Arts (Verona) and Santa Paola Institute (Mantua).

**Sabrina Tegani** - Graduate Gemologist (Gemological Institute of America), she learned gemstones cutting at IRIGEM (Rosà, VI), She worked in the Gemological Education Certification Institute (Milan) as analyst gemologist and gemology educator. Activity in antique and modern jewelry, among the others as rough diamonds analyst and consultant, recently started her business with her sole proprietorship "Rialto".

#### References

- Adamo, I., Pavese, A., Prosperi, L., Diella, V., Merlini, M., Gemmi, M. and Ajò, D. (2005) "Characterization of the new Malossi hydrothermal synthetic emerald", *Gems & Gemology*, 41(4), pp. 328-339.
- Ajò, D., De Zuane, F., Caramazza, G., Gambaro, M., Guadagnino, E., Morucchio, M., Polato, P. and Rizzo, G. (1999) "Spectroscopic techniques for the determination of the iron redox state of glass and their direct application in the glass factory", *Glass Technology*, 40(4), pp. 116-120.
- Ajò, D., Favaro, M. L., Reyes-Valerio, C., Chiari, G. and Giustetto, R. (2000) "Characterization of Maya blue by photoluminescence spectroscopy". XXXII International Symposium on Archaeometry (México City). Proceedings (British Archaeological Reports). CD-Rom.



- Ajò, D., Chiari, G., De Zuane, F., Favaro, M. L. and Bertolin, M. (1996) "Photoluminescence of some blue natural pigments and related synthetic materials". Proceedings of the V International Conference on non-destructive testing, microanalytical methods and environmental evaluation for study and conservation of works of art (Budapest). pp. 33-47.
- Aula, F., Ajò, D., Chiari, G., Colucci, G., Compagnoni, R., Davit, P. and Mirti, P. (1997) "Studi analitici sui materiali del Jubé" in "S. Maria di Vezzolano-II Pontile: Ricerche e Restauro" (Soprintendenza Beni Architettonici e Ambientali Piemonte, Fond. Cassa Ris. Asti, Soc. Ed. U. Allemandi & C.), pp. 104-107.
- Bedini, A., Ehrman, S., Nunziante Cesaro, S., Pasini, M., Rapinesi, A. and Sali, D. (2012) "The Vallerano diamond from ancient Rome: a scientific study", *Gems & Gemology*, 48(1), pp. 39-41.
- Berke, H. (2007) "The invention of blue and purple pigments in ancient times", *Chemical Society Reviews*, 36(1), pp. 15-30.
- Bonifazi, G., Capobianco, G., Paladini, A., Prestileo, F., Serranti, S., Toschi, F. and Trojsi, G. (2017) "Caratterizzazione degli intonaci dipinti. La caratterizzazione delle superfici dipinte", in Pensabene P. and Sfameni C. (eds), *La Villa Romana di Cottanello. Ricerche 2010-2016*. Bari: Edipuglia, pp. 209-222.
- Chiari, G., Ajò, D., Reyes-Valerio, C. and De Zuane, F. (1999) "Application of photoluminescence spectroscopy to the investigation of materials used in works of art", in Proceedings of the 6th Internat. Conference on non destructive testing and microanalysis for the diagnostics and conservation of the Cultural and Environmental Heritage (Rome, 1999), AIPnD and Istituto Centrale del Restauro. Rome: Euroma, Vol I, pp. 1717-1726.
- Colosi F. and Prestileo F. (2017) "Censimento speditivo e analisi del degrado dei dipinti murali", in Pensabene, P. and Sfameni, C. (eds), *La Villa Romana di Cottanello. Ricerche 2010-2016*. Bari: Edipuglia pp. 187-192.
- Dyer, J. and Sotiropoulou, S. (2017) "A technical step forward in the integration of visible-induced luminescence imaging methods for the study of ancient polychromy", *Heritage Science*, 5, pp. 24-45.
- Forbes J.R. (1955) "Studies in ancient technology", III, p.216. Leiden: E. J. Brill.
- Galiani, B. (1758) "L'architettura di M. Vitruvio Pollione". Translated from "De Architectura" Liber VII, Chapter 11, p.293. Naples: Stamperia Simoniana.
- Giarola, M., Mariotto G., Barberio, M. and Ajò, D. (2012) "Raman spectroscopy in gemmology as seen from a 'jeweller's' point of view", *Journal of Raman Spectroscopy*, 43(11), pp. 1828–1832.
- Haüy, R.J. (1801) "Traité de minéralogy", Vol.IV, Chapter VII, pp.358-360, Imprimerie de Delance, Paris.
- Higa, T. (1993) "Effective micro-organisms: an earth saving revolution", Vol. 1, Sunmark Publishing, Tokyo.
- Higa, T. (1998) "Effective micro-organisms: an earth saving revolution", Vol. 2, Sunmark Publishing, Tokyo.
- Maini, L., Ajò, D. and Ehrman, S. (2006) "The identification of gemstones by photoluminescence: synthetic and natural Mg-Al spinels" in Proceedings of the 4th International Gemological Symposium & GIA Gemological Research Conference (August 2006, S. Diego, California, U.S.A.). *Gems & Gemology*, 42, p. 125.
- Petushkova, J.P. and Lyalokova, N.N. (1986) "Microbiological degradation of lead-containing pigments in mural paintings", *Studies in conservation*, 31(2), pp. 65-69.
- Plesters, J. (1966) "Ultramarine blu, artificial", *Studies in conservation*, 11(2), pp.76-91.
- Plinii Secundi, C. (1873) "Naturalis Historia", Volume V, Libro XXXII, p. 68. Berolini apud Weidmannos.
- Pozza, G., Ajò, D., Chiari, G., De Zuane, F. and Favaro, M. L. (2000) "Photoluminescence of the inorganic pigments egyptian blue, Han blue and Han purple", *Journal of Cultural Heritage*, 1(4), pp. 393-398.
- Reiche, I. Vignaud, C. and Menu, M. (2000) "Heat induced transformation of fossil mastodon ivory into turquoise 'odontolite'. Structural and elemental characterisation". *Solid State Sciences*, 2(6), pp. 625-636.
- Reyes-Valerio C. (1993) "De Bonampak al Templo Mayor - El azul Maya en Mesoamérica". Colección América Nuestra, Vol. 40, América antigua. México: Siglo Veintiuno Editores.
- Riederer J. (1997) "Egyptian blue", in West FitzHugh E., (ed.), "Artists' pigments. A handbook of their history and characteristics" (a National Gallery of Art U.S.A. publication), Vol.III, pp. 23-46.
- Sánchez del Río, M., Domenéch, A. M., Doménech-Carbo, M. T., Vázquez de Agredos Pascual, M. L., Suárez, M. and García-Romero, E. (2011) "The Maya blue pigment", in Galan, E. and Singer, A. (eds) *Development in palygorskite-sepiolite research – A new outlook on these nanomaterials*, Chapter 18, pp. 453-481. Elsevier.
- Shaw, P. (1738) "The Philosophical Works of the Honourable Robert Boyle", Vol.III, p.105. London: Printed for W. Innys and R. Manby, and T. Longman.

# The colours of the ancient Greek architecture

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## **ABSTRACT**

The use of colour has developed over time with the evolution of culture, the arts, commerce and the expansion of exchanges and knowledge on materials and construction techniques. In particular, in architecture, every intervention on new or existing buildings is conceived and realized without neglecting the chromatic aspect, both because colour represents a characteristic inherent in the material, and therefore inseparable from it, and because most of the time it is seen as an added value, which transcends the material itself and is expressed through different channels. If we think of the lively and extensive polychromy that covered the ancient architectures (here the interest is directed in particular to the Greek architecture), this presence can certainly contribute to a more correct definition of the overall architectural aspect. The idea that ancient Greek architecture was characterized by the absence of colour comes from a false vision; its origins are to be found in the dispute over the primacy of the arts, which arose during the Renaissance, which saw the opposition and a progressive estrangement between the “form” (seen as an instrument of ratio) and colour (the result of the most irrational temptations of the senses). Only in the mid-nineteenth century, in contrast to the current opinion still strongly conditioned by the neoclassical heritage, the theme of the use of colour in the restitution of an ancient building was addressed. This first and decisive stance was followed by heated discussions, but also numerous other contributions, solidly documented by archaeological evidence, which helped to overcome the residual resistance on the part of the most conservative scholars and to consolidate a less idealized image of the ancient buildings. The contribution analyzes the most significant phases within this process of re-appropriation of a more coherent and less idealized identity by ancient architecture, highlighting the importance of colour in the phases of reading and interpreting forms now lost.

**KEYWORDS** Ancient Greek architecture, myth of white, ornament, architectural orders, polychromy, chromatic research

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## 1. Introduction

Since the dawn of civilization, colour has always been the most popular and widespread expressive tool, it was chosen for ornamental, symbolic or representative purposes, but also to meet the perceptual needs of the whole. Throughout history, the use of colour has developed in parallel with the evolution of the arts, culture, commerce and the expansion of exchanges and knowledge of materials and pictorial and constructive techniques. We could say that there is no surface, no volume, no body in general, that avoids being interested in chromatic conditioning.

As Pietro Zennaro states in his book *Colore e luce in architettura. Fra antico e contemporaneo*, «colour is not just a perception or a material, or a frequency of light, ...colour is culture» (Zennaro, Gasparini, Premier 2010). When used culturally, colour hides and dissembles other meanings, which for some reason are not aimed at everyone, but at the same time it privileges and gives meaning to what it protects. Each epoch has been able, or “wanted”, to see and use only a few colours, setting aside the infinity of variations of which this visible phenomenon is constituted [1]. Therefore, the use of colour can be considered a privileged filter in the reading and interpretation of the past. Architecture depends on its own time and colour is to be understood as the crystallisation of the structure of society and the individuals that make it up (Albarello 2014). In this regard, it can certainly be said that considering the presence of the lively and extensive polychromy that covered the ancient architecture can contribute to a more correct definition of the overall architectural aspect, avoiding the possibility that the current state of conservation of most of the ancient buildings may still lead to the erroneous association between ancient architecture (and art) and lack of color.

## 2. The myth of white in ancient art and architecture

In architecture (and in art in general), the “myth of white” has a “historical” dimension that over the centuries has taken on different meanings: from the aesthetic misunderstanding following the archaeological discoveries of the eighteenth century, which influenced neoclassicism, through the analysis of spontaneous architecture of the Mediterranean and European rationalism, to arrive at minimalism and contemporary architecture. A myth destined cyclically to rise again with different attributions of meaning, at the same time equal and different. The myth of white, through Winkelmann's aesthetics, has become

an immutable ideal of beauty, formal purity, sobriety, rationality and abstraction. «If myth is a language, architecture as art feeds on it» (Albarello 2014).

Colour is not an exact science, but its field covers an area of borderline between art and science, between physics and psychology and since forever «every philosopher scientist has stopped with suspicion to consider colours: they represent the laws of mutation, seduction, non-truth, the suddenness of the opposite phenomenon; the irrevocability of a strong message and at the same time a passing destiny (Eros was born from Iris)» (Brusatin 2000). If we refer to the Sophists, the “colourful speeches” recall some truths close to things and “colouring the speeches” involves the creation of inconstant images and suggestions, to make believe some truths in place of others. It is well known that in the Greek world the theme of suspicion towards colour has manifested itself more openly: the Pythagoreans, for example, consider it profoundly extrinsic, “superimposed” and purely evocative (Brusatin 2000).

This type of consideration would be objectively confirmed by referring to the etymology of the word colour, whose root can have three derivations: from Sanskrit “*kalanka*” (stain) and “*kala*” (black, dark); from Greek *κλεινός* (black, dark), as well as from Latin “*celare*” (hide, in the sense of making it dark) (resource: [www.etimoitaliano.it](http://www.etimoitaliano.it)); therefore, it is clear that in the original meaning of the term there is a negative meaning, as if the colour served only to “stain, obscure and hide”.

In the real artistic production, the “form/colour” contraposition begins with classical philosophy and continues with the theoretical convictions of the Renaissance with a neoplatonic background. The contrast between drawing and colour, a meditation already academic in itself and of late 16th century, seems to be inspired by a passage from Aristotle's Poetics that unmistakably assigns a primacy to the drawn form: «whoever, in fact, casually throws down the most beautiful colours, would never delight the sight as whoever has drawn a figure in white» [2].

In the fifteenth century, with the advent of the geometric science of perspective, in an even more evident way the reproductive arts were considered bearers of wisdom and truth, while the world of colours remained within the sphere of “seductive and apparent”. «Therefore, alongside a primacy of the historical sovereignty of the arts of drawing, there is the discontinuous production of colour, always removed from safe laws and devoted to the uncertain destiny of the life and fortune of the individual artist» (Brusatin 2000).



Fig. 1. The Laocöon Group from an original bronze statue from around 140 BC, Vatican Museums. Photo by the author.

In 1506 the discovery of the Laocöon Group (fig. 1) decrees the undisputed victory of the white; from some scholars this discovery is considered the first true perceptive-aesthetic “falsification” of the ancient sculpture. The work of art, during its millenary stay under the ground, had obviously lost its original colour. This extraordinary effect of intense white of the masterpiece had the inevitable consequence of dazzling all the artists of the time, including Michelangelo, determining such a strong impact on the aesthetic taste of the time, to impose as predominant artistic genre the sculpture not painted, preferably of nude marble (resource: <http://post.uniurb.it/?p=5467>).

Winckelmann, with his book *Gedanken über die Nachahmung der griechischen Werke in der Malerei und Bildhauerkunst* (Thoughts on the imitation of Greek works in painting and sculpture) of 1756, succeeds in definitively “authenticating” and sealing the myth of white in classical antiquity, raising the white marble sculptures to a tangible sign and symbolic image of the aesthetic ideal (Winckelmann 1756). And this happened at the very time when archaeological discoveries and closer examinations of the works brought concrete evidence that the

monuments of classical antiquity, such as the Parthenon of Phidias, were in fact colored, something that in fact also the sources spoke of, as was able to demonstrate Quatremère de Quincy (resource: <http://post.uniurb.it/?p=5467>). In fact, Pliny the Elder, Pseudo Aristotle, Theophrastus and Vitruvius provide detailed descriptions of the raw materials used in architecture, the procedures for the preparation of colorants and even their prices (resource: <http://www.arkeomania.com/colorisculturagreca.html>).

As the archaeologist Antonio Giuliano [3] reports in his rich manual on Greek art, the sculptures of the Parthenon were all in marble, enriched with bronze details, probably gilded, while the sculptures were certainly painted. Traces of red and blue have been found in several places, so it can certainly be said that the bottom of the metopes was painted with red and blue and that the base of the frieze was blue. All this had to be enriched by details and figures in gilded bronze or coloured red, green and gilded. According to the author, however, the polychromy was not very intense, as it was used mainly to give prominence to the figures (fig. 2) (Giuliano 1987).





Fig. 2. The Acropolis of Athens: the Parthenon and the Erechtheum in a colour reconstruction. Images from National Geographic, Archeologia. Le città del passato ricostruite, Macrolibros, Milano 2017.

## 2.1. Winckelmann and the imitation of the Ancients

The heated dispute over the primacy of the arts reached its peak in the 18th century with Johann Joachim Winckelmann, one of the most important and influential art historians, archaeologist and critic, considered the father of art history.

His thought is rich and contradictory, crossed by a latent critique of contemporary society, strained between the almost desperate search for the intangible norms of a timeless and superhuman perfection and the fascinating discovery of its incarnation in a place and in a determined time: the Athens of the fifth century (Pommier 1991).

Winckelmann exalts the whiteness and the absence of colour as the signature of the absolute immaterial purity of the masterpieces of classical statuary, with a double objective: «to preserve the universality and the historicity of the Classic and to favour the reproduction of the ideal Beauty in contemporary art by imitating ancient models» (Winckelmann 1763).

Greek art (for Winckelmann the space of time between Phidias and the age of Alexander the Great circumscribes the period during which the art of antiquity reaches its peak, identifying a peak of classical perfection) is not only considered as “worthy object of study”, but also, and above all, as an object of imitation, to find “the rules” to be applied in your own *modus operandi*.

The crucial problem that emerged from Winckelmann's aesthetic reflection was the impossibility of clearly establishing “the rule and the canon” to define what true beauty is and prevent Beauty from sinking into the abyss of subjectivity, in the same way as individual judgment and taste. To oppose this subjectivist corruption, Winckelmann

resorts to the works of antiquity, to what he defines as “*exempla*”, concrete, visible objects, characterized by pure form, without ornament. Greek art elevates itself «above matter» (Testa 1999), passing from the sphere of the empirical to the spiritual and the absence of ornaments and colours contributes to this sublimation. For Winckelmann, «a beautiful body will then be all the more beautiful when it is white, and when it is naked it will seem larger than it actually is» (Winckelmann 1764). The essence is manifested in the naked white body, in the whiteness of the ascetic absence of colour of the marble and in the expression of the uncontaminated interiority, that is, without the degradation caused by the addition of colour. Taking up the Platonic ideology, according to which colour is intended as a misleading expression of passion and works in the field of evil, Winckelmann's idea of colour is linked to the transience of life, to the body, to matter, to temporality, to appearance and to sensitivity. Colour is therefore accessory and inessential and over time is doomed to lose its expressive power.

Winckelmann reserves the same type of treatment for ornament: «he implements a precise theoretical strategy aimed at neutralizing the subversive potential of which the ornament is considered the repository because of its intrinsic vocation to obscure the purity and perceptive clarity of the form. For Winckelmann the form must be based on the principle of simplicity, and therefore must appear absolutely naked and devoid of any ornament, in its original epiphany» (Testa 2009).

In his famous work *Anmerkungen über die Baukunst der Alten* (Observations on the architecture of the ancients) Winckelmann tries to temporalize the affirmation of the ornament by describing it as «a pernicious pathological alteration that, over time, has corrupted an origin-essence

conceived as unadorned purity: After all the essential parts of Architecture were invented, the ornate were thought of, which could serve to embellish the buildings» (Winckelmann 1762). In his idea of aesthetics, the ornament represents the deplorable emblem of a Baroque ideal, which cyclically returns to manifest itself over time and to ruin the classic perfection of the form, in order to tickle the lowest instances of individual sensoriality. «When the ornament is superimposed on the form, the latter is literally erased: with the ambition of making it richer, the ornament annihilates it» (Testa 2009). Taking up a definition of Kant's drapery used for sculptural works: «those things that do not belong intimately, as a constituent part, to the total representation of the object, but only as exterior accessories, increasing the pleasure of taste», Winckelmann compares the ornament in architecture to the *parergon* for the nude body in sculpture. Ornament is in fact added to what is essential to embellish it, making it more vividly perceptible to the senses but, in his opinion, without «making a homogeneous contribution to the pleasure of form» and moreover blurring its contours, at the expense of the perfection and beauty of the work (Winckelmann 1764). The use of colour and ornament is therefore an evil that has marked discontinuity, fracture and differentiation within the cycle of historical development of ancient architecture: «When good taste began to lose, and when appearance was praised more than reality, ornaments were no longer considered as mere accessories; but places, which until then had remained naked, were enriched. Then came the petty taste in Architecture: for, as Aristotle says, the rule is that when each part is small the whole still has to be small. It happened to Architecture as to the ancient languages, which became richer as they lost their energy and their beauty, as it is easy to prove taking as an example the Greek language and the Latin language: and since the architects saw that they could not surpass or even equal their predecessors in the beauty of the works, they tried to overcome them in wealth and profusion» (Testa 2009).

This theorization on the role of absolute aesthetic model attributed to the Antique has been fundamental for the neoclassical art that, recovering and imitating that deep-rooted idea of purity and compositional rationality of the Greek art, has marked and identified an artistic season inspired to the ancient models, of which one of the greatest representatives has been the sculptor Antonio Canova (fig. 3).

### **3. Polychromy in ancient Greek architecture**

The Italian painter Raphael (1483-1520) was the first to realize that the ancient world, as it appeared to his eyes

and as it was represented, was only the faded echo of that richness that necessarily had to characterize its artistic value: «those famous works» are defined by him as «the bones of the body without flesh» [4]. When he speaks of “flesh” he obviously refers to the decorations, the richness of the covering materials and the colours. He invests in his dream of reconstructing the ancient Rome, now lost, all his sensitivity and attention to the documentation in his possession, managing to draw, from that confused set of incentives and impulses, an all-round view of the ancient architecture with an almost scientific method (Di Teodoro 1994).

More than two centuries later, in the drawings of the architects-archaeologists Stuart and Revett, authors of the *Antiquities of Athens* (1762) a book containing their daring plan to study and represent the most important monuments of the city of Athens and its surroundings, there is a first, pale interpretation of some buildings with painted ornamental parts, but which is not explained (Stuart, Revett 1762). There is therefore a lack of specific attention to the use of colours, which was found about sixty years later in the thought and works of Quatremère de Quincy.

The famous French archaeologist and essayist assigns colour a leading role in the aesthetics of Pericles' age, and defends its use as a valid and tasteful choice, demonstrating its original effect with a series of hand-coloured reconstructions. His drawings of the colossal Chryselephantine statues by Pheidias are famous, characterized by the combination of different materials and therefore polychrome: Zeus of the frontispiece is the colour of ivory in the nude parts and the colour of gold in the clothes, decorated with sober ornamental motifs in blue and red. This study by Quatremère is the first sign of an estrangement from white, characteristic of neoclassical aesthetics at the end of the 18th century and establishes itself as a point of reference for subsequent scholars and interpreters of ancient art and architecture (Quatremère de Quincy 1814).

In the mid-19th century, for example, the Franco-German architect and archaeologist Jakob Ignaz Hittorff presented his research on colour as a transposition into architecture of the studies on sculpture carried out by the great French master. His restitution of the Temple B of Selinunte, characterized by an amazing chromatism, is famous (fig. 4) (Rocco 1994). It is one of the smallest sacred buildings in the city, located on the Acropolis, on which Hittorff concentrated much of his research, which resulted in the publication *l'Architecture antique de la Sicile*.



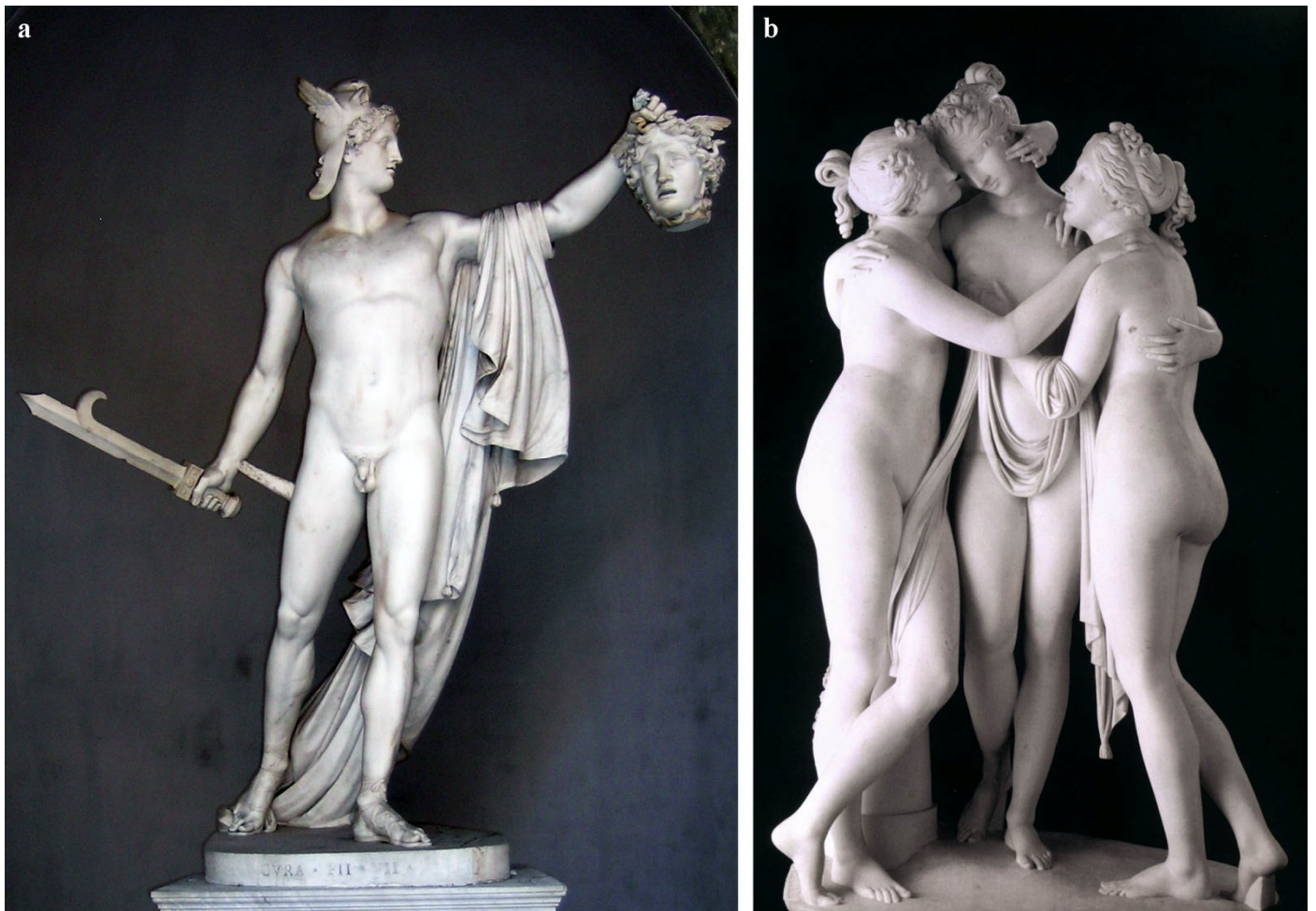


Fig. 3. Antonio Canova: a) *Perseus Triumphant* (1797-1801), Vatican Museums, photo of the author; b) *Three Graces* (1812-1817), Hermitage Museum of St. Petersburg. Image from [www.ergsart.com](http://www.ergsart.com).

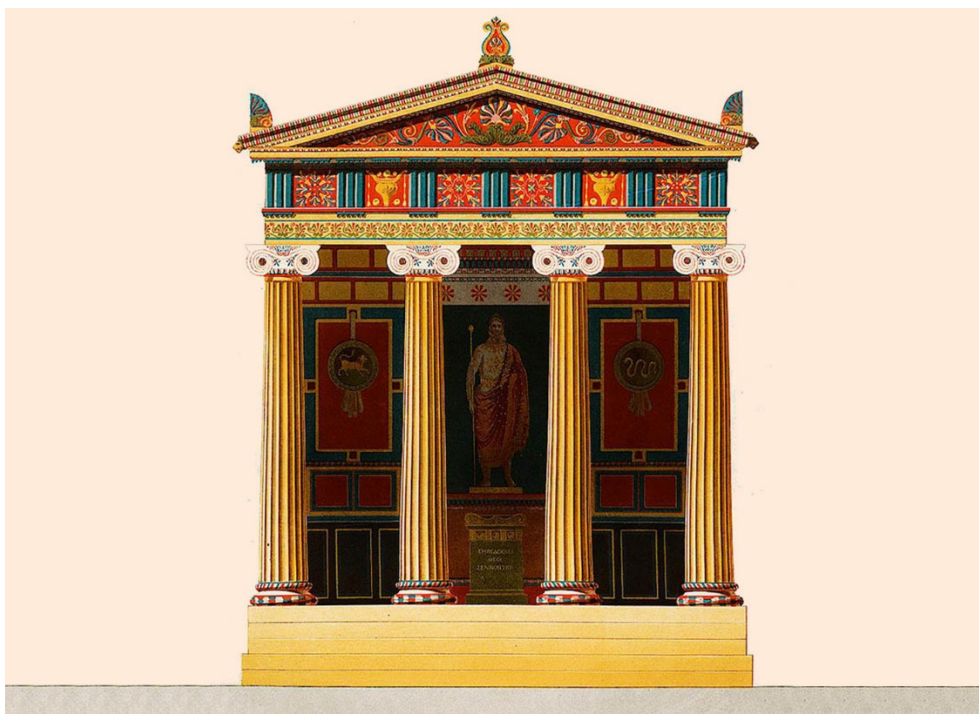


Fig. 4. Jakob Ignaz Hittorff, graphic representation of Temple B of Selinunte. Image from [www.pinterest.it](http://www.pinterest.it).

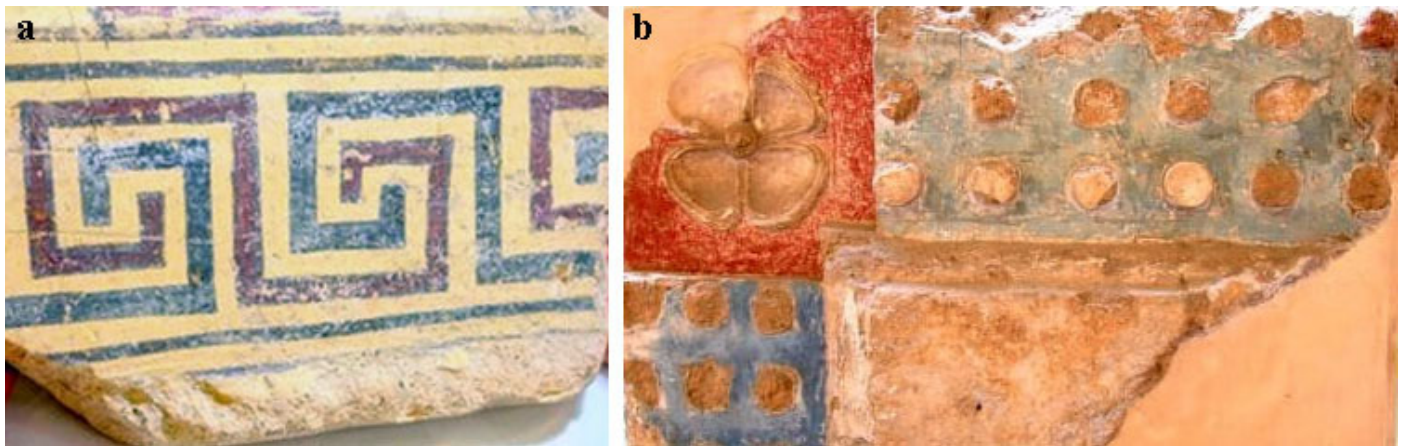


Fig. 5. a) Fragment of a *sima* found at the Acropolis of Selinunte by the team of Professor Clemente Marconi; b) fragment of the *geison-sima* of the pediment, Palermo, Regional Archaeological Museum. Details of images taken from the site <http://www.castelvetranoselinunte.it/gli-straordinari-colori-dellantica-selinunte/>.

Although the Temple B is not the main object in the book, its presentation is in fact the most articulated and detailed in its decorative aspect. Hittorff reconstructs the building in plan and elevation, characterising it in all its parts with a rich polychrome decoration (Hittorff 1870). The principles that guided Hittorff in the reconstruction of the temple are published in the *Annales de l'Institut de correspondance archéologique* of 1830, in his essay *De l'architecture polychrome chez les Grecs* [5]: first, he states that the system of polychrome architecture is valid throughout the history of the Greeks, understood as one of the most suitable means of adding charm to the majesty of their temples; such a system would be the only means available to Greek architects to integrate buildings into the context and thus in perfect harmony with nature; and finally, the full application of this system to a building of antiquity makes it absolutely worthy of the perfection and beauty of Greek Art (Hittorff 1830). According to Hittorff, the origins of colour in Greek civilization are very distant, we could say almost primitive; the idols in coloured wood, arrived from Egypt, would have suggested the use of colour in architecture. The numerous traces of colour still visible on some important stone or marble buildings, including the Parthenon, the Erechtheum and the Theseion in Athens, the temple of Aegina, and the temple of Apollo in Bassae would be proof of an uninterrupted use of colour throughout the history of the Greeks. According to the architect, the silence of ancient sources on the use of polychromy in architecture cannot, therefore, be used as evidence for its absence, but can even derive from the opposite motivation, namely that the colour was so widely diffused as not to strike for its uniqueness. However, his research and related results are characterized by an evident distortion of the archaeological reality, which probably derives from the need to find in the past the approval of his work (Marconi 2008).

The recent researches conducted by Professor Clemente Marconi [6], through the discovery of architectural terracottas that still preserve the original polychromy of the Temples of Selinunte (fig. 5), shows the arbitrariness of the reconstruction of Temple B by Hittorff [7]. In fact, he would not have limited himself to using the documentation relating to the building, following a rigorous philological method, but he would have used a series of sources, both literary and recovered from the comparison with other monuments, in order to produce an integral reconstruction of the Temple.

The work of the French architect, although characterized by errors of archaeological interpretation, represents still a very important contribution to the broad and complex theme of polychromy in the ancient world, which was followed by heated discussions, contrasts, but also further relevant evidence to support and consolidate a less idealized image of ancient monuments (Rocco 1994).

According to the studies of Professor Giorgio Rocco [8] on ancient architectural orders, polychromy is not a specific character of a particular order, but would affect all orders, without distinction. However, careful analysis and comparisons have shown that colour was never used randomly, but with precise functions, with inevitable differences between the various architectural orders. In Doric architecture, for example, the presence of colour is manifested in two distinct forms: the first sees colour as an aspect complementary to architectural decoration in the strict sense, especially in the mouldings, helping to accentuate the highlights and complete the reproduced motif in detail (fig. 6); the second concerns chromatism in large backgrounds that mark the different elements of the order (fig. 7) (Rocco 1994). In the archaic age (VII-VI sec. b.C.), the colours used for the mouldings are the warm





Fig. 6. The colour used on the mouldings: a) Athens, Acropolis, sima decorated with palmettes (about 480 B.C.); b) Corinth, straight sima with acanthus spirals with leonine protomes (IV century B.C.). Images taken from: Rocco, 1994.

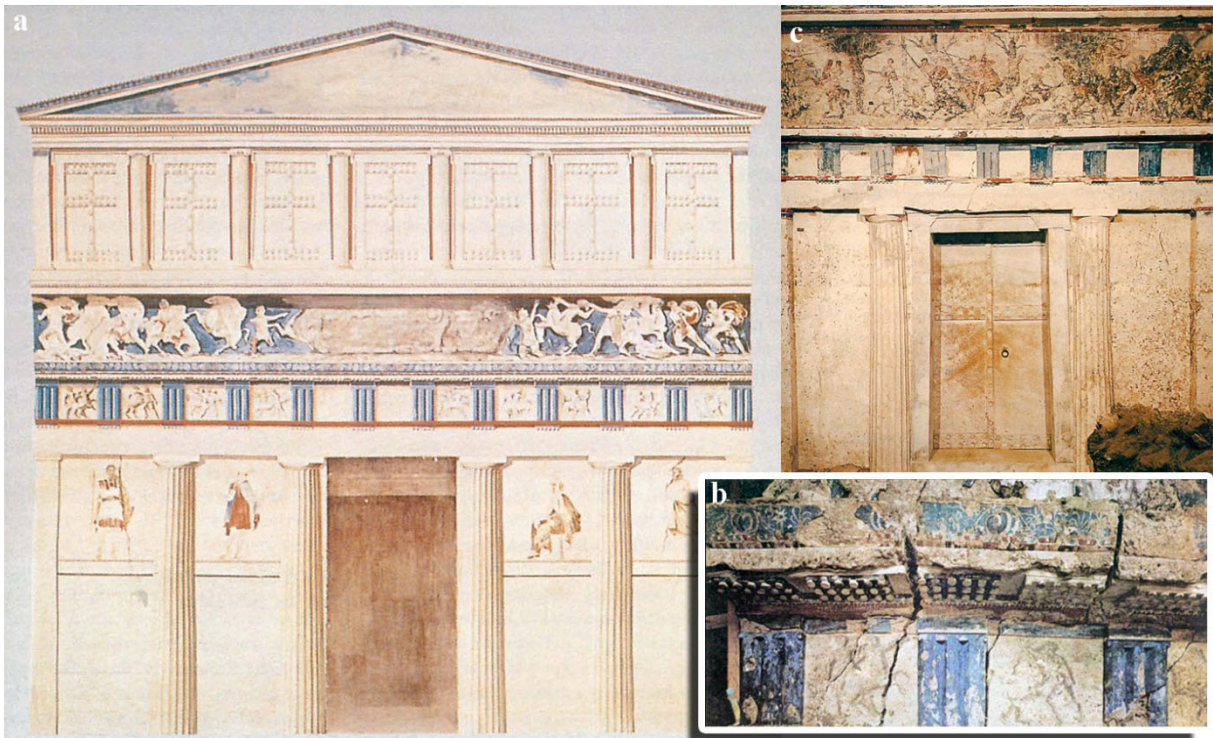


Fig. 7. The color used to scan the elements of the order: a) Lefkadia, Great Tomb, facade drawing. Image taken from HELLMANN, 2002; b) Lefkadia, Great Tomb, detail of the trabeation that preserves the original colour backgrounds of the elements of the order and the mouldings unaltered; c) Vergina, Tomb of Philip, elevation of the monument that preserves the original colouring of the different elements of the order. Images taken from Rocco, 1994.





Fig. 8. a) Athens, Acropolis, archaic votive capital with globular echinus; b) Delphi, Treasure of the Siphni, floral motif on the lower surface of the geison; c) Delphi, Treasure of the Siphni, detail of the frieze. Images from Rocco, 2003.

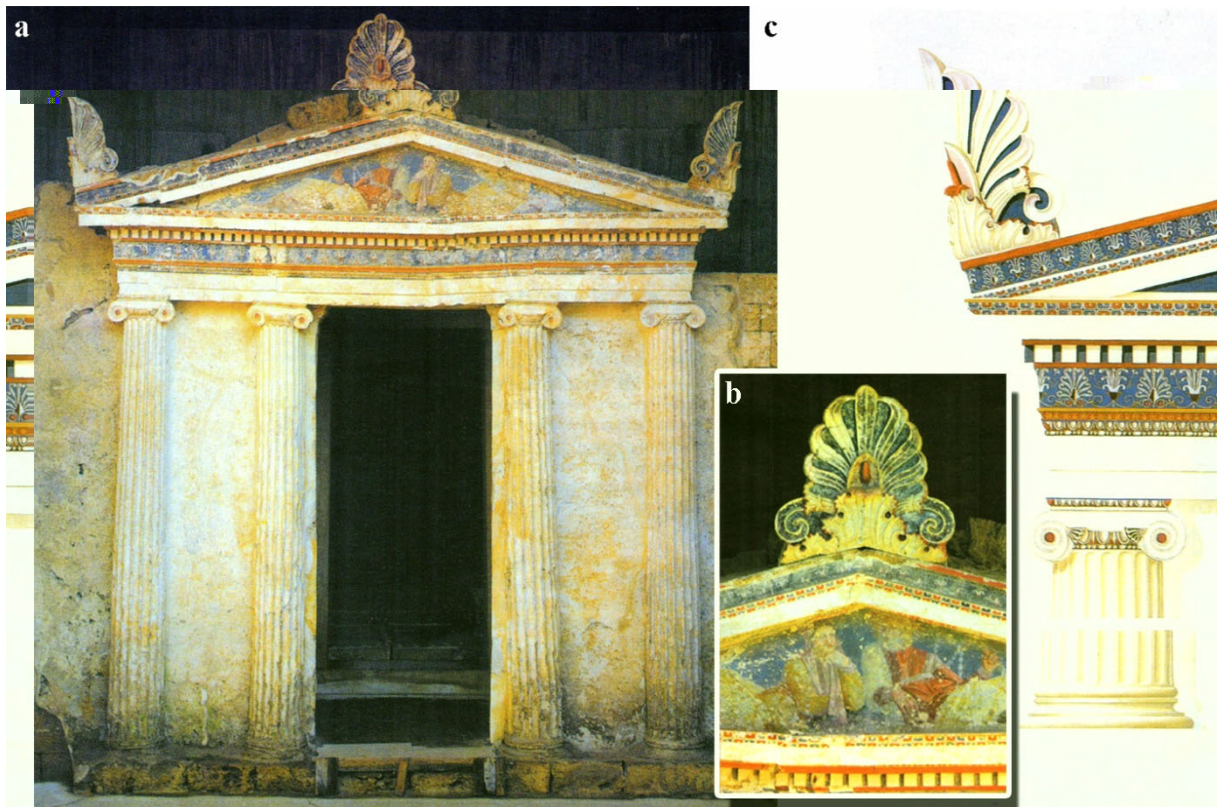


Fig. 9. Lefkadia, Tomb of the Palmettes, first half of the third century BC. Excellent state of preservation of the painted decoration. a) Prospect; b) detail of the pediment; c) detail of the pediment in a color reconstruction. Images taken from: Rocco, 2003.





Fig. 10. Examples of architectures and decorative devices that testify to the evolution in the use of colors over time. Images taken from Hellmann, 2002.

tones of brown and ochre, but also red, green and blue, as well as white and black, mainly used for the general design and the borders of the various motifs; later on, red and blue prevail, flanked by white, black and often golden yellow. Instead, the choice of colouring the load-bearing structures probably responds to a logic aimed at accentuating highlights and underlining correspondences, in addition to the desire to lighten the shadows that the strong sunlight would create on the light surface of the marble. A very important aspect that emerges from this careful examination of the chromatic characteristics in the Doric order is the desire to underline the correspondence between some elements of the order: regula, triglyph and mutulo, for example, are correlated not only by a uniform width and by the arrangement on the same axis, but also by a common colouring that contributes to increasing their interrelation (fig. 7). The use of complementary colours, arranged in close alternation according to a combination that appears both in the decorative motifs and in the colouring of the various elements, consciously aims to visually accentuate protrusions and recesses, in a formal research that takes concrete form in the accentuation of plasticism, at the same time contributing to making the internal articulation of the order more legible (Rocco 1994). In Ionic architecture, on the other hand, unlike the Doric order, the colour is limited to the more properly decorative elements, in particular the mouldings, the sima and the frieze, if present; the use of colouring the structural or functional elements of the order is not supported by objective evidence; the surfaces free of decorations are left in the natural colour of the marble or painted white. Some examples of capitals found in Athens are emblematic, with the characteristic decoration of the leaves in alternate colours, red and green, as well as some parts of entablature found in Delphi, characterized by the alternation of the usual colours, already found for the Doric order: yellow gold, green, red and blue (fig. 8). But the most significant documents are certainly represented by the Macedonian underground tombs of the Hellenistic period. Their concealment under the ground has allowed

for a state of conservation that is sometimes surprising, with the stucco covering that still bears the lively colouring of the various parts almost intact (fig. 9) (Rocco 2003).

#### 4. Conclusions

It is clear that the use of colours for the Greeks has changed over the centuries, from a simple contrast of light and dark, typical of the geometric era, to the so-called “archaic triad”, characterized by games of red and white on a blue background, and then move on to richer chromatic manifestations, with the addition of metals and natural inorganic pigments (fig. 10) (Hellmann 2002). The documentation on the use of colour in ancient architecture, which continues to be enriched by new finds, thus highlights a chromatic research that contrasts significantly with the current state of most of the most famous monuments, leading the image of Greek architecture to a context historically and culturally more consistent and less idealized than that which has been handed down to us, because of the persistence of neoclassical ideals, which have ignored or simply denied incontrovertible archaeological acquisitions (Rocco 2003).

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#### 6. Conflict of interest

The author declares that nothing has affected her objectivity or independence in the production of this work. There are no actual or potential conflicts of interest, including financial, personal or other relationships with other people or organizations within three years of beginning the submitted work, that could inappropriately influence, or be perceived to influence, this work.

## 7. Short biography of the author

**Rossana Netti** is an architect, Ph.D. in Cultural Heritage and since 2018 researcher at the Department of Architecture and Design (DAD) at the Polytechnic of Turin. Her research activity concerns the study of methods and advanced digital technologies for the survey, enhancement and communication of Cultural Heritage, from the acquisition of field data to their processing and integration in virtual reality environments.

## Notes

[1] Interview to Pietro Zennaro, *The value of colour in architecture*, on [www.laterizio.it](http://www.laterizio.it).

[2] Aristotele, *La Poetica*, 1450a, 1-3.

[3] Antonio Giuliano (1930 – 2018) was an Italian academic and archaeologist among the major of the second half of the twentieth century.

[4] "...quelle famose opere, che oggidi più che mai sarebbero florenti e belle, furono dalla scelerata rabbia e crudel impeto di malvagi uomini, anzi fère arse e distrutte; ma non però tanto che non vi restasse quasi la macchina del tutto, ma senza ornamenti, e - per dir così - l'ossa del corpo senza carne..." These are the words with which Raphael, through the elegant speech of Baldassarre Castiglione, described the ruins of the antiquities of Rome in his famous letter to Pope Leo X, as he was about to embark on one of his most grandiose projects: the survey and graphic reconstruction of ancient Rome. (Borghini, Carlini 2011).

[5] Hittorff presents his theory of polychromy for the first time in detail in *De l'architecture polychrome chez les Grecs, ou restitution complète du temple d'Empédocle dans l'acropole de Sélinunte*, a memory read in front of the members of the *Institut de France* and immediately published (1830) in the *Annals of the Institut de correspondance archéologique*. According to his theory, Greek architecture cannot be understood without admitting the use of polychromy.

[6] Clemente Marconi is Full Professor of Classical Archaeology, Department of Cultural and Environmental Heritage, University of Milan; James R. McCredie Professor of Greek Art and Archaeology and University Professor Institute of Fine Arts, New York University; Director, Institute of Fine Arts-NYU and UniMi excavations on the acropolis of Selinunte.

[7] In 2005 Professor Clemente Marconi undertook a project of documentation, research and excavation in the area of Temple B of Selinunte, sponsored by the Institute of Fine Arts of New York University, in agreement with the Superintendence for Cultural and Environmental Heritage of Trapani.

[8] Giorgio Rocco is an architect, Full Professor in History of Ancient Architecture at the Polytechnic of Bari.

## References

Albarelo C. (2014), *Aléthosphère: i colori dell'Altro*. In: Zammerini M. (a cura di), *Il mito del bianco in architettura*, Quodlibet, Roma.

Borghini S., Carlini R. (2011), *La restituzione virtuale dell'architettura antica come strumento di ricerca e comunicazione dei beni culturali: ricerca estetica e gestione delle fonti*, in «Disegnarecon», dicembre 2011.

Brusatin M. (2000), *Storia dei colori*, Piccola Biblioteca Einaudi, Torino.

Di Teodoro F. P. (1994), *Raffaello, Baldassar Castiglione e la 'Lettera a Leone X'*, Bologna.

Giuliano A. (1987), *Arte Greca. Dall'età classica all'età ellenistica*, Il Saggiatore, Milano.

Hellmann, M. C. (2002), *L'architecture grecque. 1. Les principes de la construction*, Éditions A. e J. Picard, Paris.

Hittorff J. I. (1830), *De l'architecture polychrome chez les Grecs ou Restitution du temple d'Empédocle à Sélinonte.*, dans les *Annales de l'Institut de correspondance archéologique* II, Paris.

Hittorff, J. I. (1870), *Architecture antique de la Sicile, ou Recueil des plus intéressants monuments d'architecture des villes et des lieux les plus remarquables de la Sicile ancienne mesurés et dessinés par J. Hittorff et L. Zanth*, Paris [1<sup>ère</sup> ed. 1826-1830].

Marconi C. (2008), *Il tempio B di Selinunte: Hittorff, Serradifalco e la disputa sulla policromia dell'architettura greca dell'Ottocento*, *An International Journal of Archaeology*, Fabrizio Serra Editore, Pisa - Roma.

Pommier E. (direction scientifique) (1991), *Winckelmann: la naissance de l'histoire de l'art à l'époque des Lumières*, Actes du cycle de conférences prononcées à l'Auditorium du Louvre du 11 décembre 1989 au 12 février 1990, La documentation Française, Paris.

Quatremère de Quincy A. C. (1814), *Le Jupiter olympien, ou l'Art de la sculpture antique considéré sous un nouveau point de vue*, Didot frères, Parigi.

Rocco, G. (1994), *Guida alla lettura degli ordini architettonici antichi. I. Il dorico*, Liguori Editore, Napoli.

Rocco, G. (2003), *Guida alla lettura degli ordini architettonici antichi. II. Lo ionico*, Liguori Editore, Napoli.

Stuart J., Revett N. (1762), *The antiquities of Athens*, London: Printed by J. Haberkorn.

Testa F. (1999), *Winckelmann e l'invenzione della storia dell'arte: i modelli e la mimesi*, Edizioni Minerva, Bologna.

Testa F. (2009), *Le Anmerkungen über die Baukunst der Alten di J.J. Winckelmann: il testo di architettura tra continuità e fratture epistemologiche nella cultura del Secolo dei Lumi*. In: Di Teodoro F.P. (a cura di), *Saggi di letteratura architettonica da Vitruvio a Winckelmann I*, Olschki Ed., Firenze.

Winckelmann J. J. (1756), *Gedanken über die Nachahmung der griechischen Werke in Malerei und Bildhauerkunst*, Dresden, Leipzig.

Winckelmann J. J. (1762), *Anmerkungen über die Baukunst der Alten*, Dresden, Leipzig.

Winckelmann J. J. (1763), *Abhandlung von der Fähigkeit der Empfindung des Schönen in der Kunst und dem Unterrichte in derselben*, Dresden; ed. it. di Cardelli M. (a cura di), *Il sentimento del bello. L'educazione del gusto per conoscere la bellezza nell'arte*, Le Càriti Editore, Firenze, 1999.

Winckelmann J. J., (1764), *Geschichte der Kunst des Alterthums*, Dresden; traduzione it. di Pampaloni M. L., *Storia dell'arte nell'antichità*, Boringhieri, Torino, 1961.

Zennaro P., Gasparini K., Premier A. (ed) (2010), *Colore e luce in architettura. Fra antico e contemporaneo*, Knemesi.

<http://www.etimoitaliano.it/2016/10/colore.html> (last access in March 2018).

<http://post.uniurb.it/?p=5467> (last access in March 2018).

<http://www.arkeomania.com/colorisculturagreca.html> (last access in March 2018).

# Primary colors as a source of possible misconceptions: an insight into teaching and learning about color

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## ABSTRACT

In the field of science education, color can provide an interdisciplinary learning content, potentially suitable for overcoming disciplinary fragmentation and promoting in students a general attitude towards dealing with problems. However, because of its polysemic nature, it is very difficult to make students able to interpret, within the theoretical paradigm of modern science, a concept that they first learn to know through perceptual experience. As a pervasive phenomenon of our daily life, color vision gives rise, indeed, to a variety of naïve conceptions – similar to the pre-Newtonian ones – that act as a filter to the new learning contents. In this context we identified, through a historical-epistemological analysis, the ancient contrast between simple and compound colors as a source of potential misconceptions to be investigated empirically. We hypothesized we could detect some misconceptions due to the lack of awareness of the different contexts – physics, physiology of vision, painters' practice – in which the distinction between primary and secondary colors can be introduced, assuming different meanings in each one. We also believed that these misconceptions were relatively independent of the subjects' level of education (children/teachers). Then an empirical research was conducted by administering two different self-completed questionnaires to a non-probabilistic sampling of convenience made up of primary school teachers and fifth-grade pupils, respectively. The results of research on both teachers' and children's misconceptions seem to confirm what hypothesized.

**KEYWORDS** Misconceptions, Primary colors, Additive and subtractive color mixing, Teaching and learning process, Constructive theory of learning, Newton's prism

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## 1. Background

In the field of science education, color can provide an interdisciplinary learning content, potentially suitable for overcoming disciplinary fragmentation and promoting in students not a sterile accumulation of knowledge but a general attitude towards dealing with problems (Morin 1999). However, because of its polysemic nature, it is difficult to make students able to interpret, within the theoretical paradigm of modern science, a concept that they first learn to know through perceptual experience (Piana 2000; Martinez-Borreguero et al. 2013).

As a pervasive phenomenon of our daily life, color vision gives rise to a variety of naïve conceptions, similar to the pre-Newtonian ones, that are scientifically incorrect but of somewhat practical use. Within the constructivist paradigm we speak, in this regard, of commonsense knowledge, that is of mainly implicit knowledge that acts as a filter to the new learning contents (Mason 2006). Howard Gardner (2004) and Stella Vosniadou (2003), among others, highlight the negative influence that this implicit knowledge can have on students' learning outcomes and on their capacity to intentionally apply what they have learned to new problem-situations. According to the two psychologists, these intuitive "theories", which take shape in children's minds to give meaning to the world phenomena, are one of the main causes of students' elective failure in science. Far from disappearing during the school years, these naïve conceptions, tacitly internalized through daily experience and communicative exchanges, often emerge, at an unthinking level, as a cognitive resistance to reasoning according to the logic of the discipline (Martini 2018). This is a profound change from the traditional vision of learning. According to the constructivist learning theory, new knowledge is built upon what was previously learnt. In other words, the student is not a *tabula rasa* who passively receives the information transmitted by the teacher. On the contrary, she/he is an active knowledge builder who, before entering school, has already independently developed informal scientific concepts. These prior intuitive conceptions are highly resistant to change – as Strike and Posner suggest (1992) – because they are embedded within a broader conceptual ecology that consists of analogies, metaphors, methodological beliefs about "how science works", knowledge from other domains, epistemological and ontological presuppositions, religious and metaphysical beliefs. A similar position is shared by Vosniadou: on the basis of researches carried out in the field of elementary astronomy and mechanics, the psychologist hypothesizes that intuitive informal knowledge is articulated in mental models, specific theories and framework theories (Vosniadou 2003). Mental models – generated by the subject to solve problems, explain and/or predict

phenomena of the natural world – are based on specific theories that consist of information – derived from observation or culturally transmitted – concerning the properties and behavior of physical objects. In turn, these specific theories are bound to framework theories, which are characterized by ontological and epistemological presuppositions about existing entities and the nature of knowledge. These presuppositions play an important role in constructing knowledge because they constitute the set of certainties on which everyday reasoning is based.

If we extend these considerations to color vision, we can interpret the intuitive models generated by learners within two framework theories, which are compatible with some misconceptions discovered through empirical research (e.g., Anderson and Smith 1986; Şahin et al. 2008; Martinez-Borreguero et al. 2013). The first framework theory is an ontology made up of assumptions derived from informal learning through our experiences and our social interactions. It describes various characteristics of the objects, including that of having their intrinsic color [3] (e.g. Hawkins 1985, Anderson and Smith 1986; La Rosa and Meyer 1991; Feher, E. and Meyer, K. R. 1992; Haagen, C. 2014). The second, instead, concerns the epistemological dimension of knowledge and assumes that things are as perceptually appear to be. These implicit presuppositions, developed in parallel with both everyday experience and ordinary language learning, act as a filter to scientific notions taught at school, which, in turn, can be vitiated by misconceptions due to the polysemy of the concept of color. In this context, we intend to analyze students' learning difficulties by using the concept of epistemological obstacle. For this purpose, we propose a reassessment of the original concept, aimed at integrating Bachelard's and Brousseau's perspectives in light of an intentional theory of knowledge (Tomblato 2018).

The notion of epistemological obstacle is originally introduced by the French epistemologist (Bachelard 2002) to identify the causes of stagnation and even of regression that lie at the very heart of the act of cognition. In this way, Bachelard focuses attention on the psychological conditions in which scientific progress is made, concluding finally that the evolution of scientific thought requires to "know against" prior pre-scientific knowledge, which is highly resistant to change since rooted in everyday experience. Brousseau (1983) later adapts the notion of epistemological obstacle to indicate the difficulties associated with the structural complexity of concepts in the field of mathematics education. He also undermines the key role that a historical analysis of the evolution of the discipline can play in highlighting these obstacles [4]. Now, if we assume the subject-object intentional relation as a structural feature of knowledge, it is possible to make a synthesis between Bachelard's and Brousseau's

perspectives, in order to increase the hermeneutic and heuristic power of the concept. Within this framework the notion of epistemological obstacle can indeed be subjected to a double interpretation. On the one hand, it alludes to the idea that scientific contents can be conceptually understood as the objective correlates of peculiar epistemic practices [5] that appeared very “revolutionary” even to the scientists who first conceived them. On the other, it alludes to the misconceptions discovered through empirical research, which reveal the spontaneous tendency of subjects in learning to think in terms of reified concepts. Because of commonsense habits and, sometimes, as a consequence of “naïve” teaching, we, indeed, are often inclined to ignore the processes that lead to the construction of such scientific contents and provide them with their meanings (Tombolato 2018). At a methodological level, this implies two possibilities. We can employ heuristically naive physics conceptions to identify conceptual stumbling blocks within expert knowledge domain. Otherwise, we can undertake a historical-epistemological analysis of the evolution of the discipline in order to infer potential misconceptions to be subjected to empirical testing. We selected this second option and decided to focus on the dispute between Hooke and Newton on the heterogeneous nature of white light as a source of possible misconceptions.

Newton proposes the analogy between the mixing of pigments and that of colored lights, defending his thesis against the objections – empirically founded – raised by his antagonist Hooke. This is a clear evidence of how difficult is reformulating the artists’ practical knowledge of working with pigments within a scientific framework (Giudice 2009) [6]. The difference between additive mixing of lights and subtractive mixture of pigments, clarified by Hermann von Helmholtz only in 1852, is therefore historically linked to the ancient contraposition between primary and secondary colors. This distinction is still a source of confusion for a lot of students because it can be introduced in different contexts – physics, physiology of vision, painters’ practice – assuming different meanings in each one. By taking into consideration Shapiro’s article (1994), we will give a brief historical account of the genesis of this classification in order to clarify the three different perspectives (physics, physiology of the visual system, artists’ practice) from which it can be analyzed. In the “New theory about light and colors” Newton affirms the existence of two sorts of colors: “the one original and simple, the other compounded of these” (Newton 1672, p. 3082). This first general definition is subsequently modified to face the objections raised by Hooke about the nature and number of primary colors, whose difference from the compound ones is now explained in terms of refrangibility: primary

colors are those whose rays are all alike refrangible, while compound colors are those whose rays undergo a different refraction. Experimentally this leads to a double possibility. Let a beam of green light pass through a prism, it will undergo a refraction but not a dispersion, or it will be decomposed into rays of different colors (yellow and blue). Therefore, Newton argues, two rays of colored light that are perceptually identical may, however, differ in their physical composition. As Shapiro points out, by primary (simple) Newton means the “physically irreducible” colors, that is the differently refrangible monochromatic spectral colors in which white light is decomposed by a prism (Shapiro 1994, p. 618). As a consequence of Newton’s definition, there is an infinite number of primary colors due to the continuity of the visible spectrum. This statement sounds odd to Hooke, who, on the contrary, referring to the arts tradition of pigment mixing, defines as primary the basic colors from which all the others can be obtained by composition. The gap between the two standpoints is partially due to the polysemy of the term “color” which can be used with very different meanings. Strictly speaking, we should employ the locution “chromatic pigments” to refer to the colored substances used in painting, which clearly differ from the “visual color” that is the color perceived by the eye when it is stimulated by the various wavelengths reflected by such pigments. Pigments work, indeed, by selectively absorbing some wavelengths from the white light, while reflecting others which evoke in human eye the corresponding colors. (De Grandis 2000, p. 17). Although Newton and Hooke disagree on the number and nature of primaries, both make no distinction between mixing pigments and mixing lights. This assumption, almost universally accepted, will be questioned by Helmholtz only two centuries later, when he finds out the different rules applying to subtractive (pigments) and additive (lights) color-mixing processes. Thus, his discovery let us move on to a third possible way to define primary colors.

According to Young-Helmholtz’s trichromatic theory, the primary colors of the spectrum are the triad of monochromatic radiations Red, Green, Blue (RGB), which, additively combined (alternately and in different proportions), produce the entire range of colors and, as a limit case, a white light. In this sense, therefore, when referring to the primary colors of the spectrum we are concerned not with physical properties of light waves, but with the perceptual effects they produce on the visual system (De Grandis 2000, p. 75). Based on what outlined so far, we will try to unravel the ambiguity that lurks in the ancient distinction between simple and compound colors, by making explicit the different meanings underlying such a classification. Our hypothesis, indeed, is that these different meanings can be correlated with potential misconceptions to be investigated empirically.

In Newton's definition of primary colors is outlined the distinction between monochromatic spectral colors (simple), characterized by a particular wavelength (between 380 nm and 780 nm), and colors obtained by mixing lights (compound). Although, sometimes, colors belonging to the second group may appear perceptually identical to the pure spectral colors of the first group, they differ from a strictly physical standpoint, however. In other words, there is no one-to-one correspondence between wavelengths and perceived colors: an object may appear yellow, for example, because it reflects light of wavelengths around 580 nm, while absorbing all the others, or because it reflects both red and green light, whose combination yields the same chromatic sensation with different lightness perception. Therefore, the same color sensation can be produced by entirely different physical stimuli. Moving from physics to physiology of the visual system in our framework we just introduced the basic concepts of the theory of additive light colors mixing from primaries red, green and blue (RGB) and subtractive color mixing that predicts the spectral power distribution of light after it passes through successive layers of partially absorbing media from primary colors cyan, magenta and yellow (CMY). Identified as the set of subtractive primary colors by a commission of international experts, the pigment colors cyan, magenta and yellow act as filters to white light in order to produce the additive triad (RGB). Superimposing magenta and yellow filters we get red light, cyan and yellow filters we get green light, magenta and cyan filters we get blue light. Finally, black results from the superposition of the three subtractive colors respectively (De Grandis 2000, p. 18).

In summary, in the first case a physical definition of "simple" colors in terms of monochromatic rays of light (that is rays of a determinate wavelength) is provided. In the second case, with reference to the physiology of the visual system, the primary colors are identified with the RGB additive color model in which red, green and blue light are added together in various ways to produce all the other colors. Finally, the subtractive primaries are those basic colors (De Grandis 2000, p. 17 note 1) used in painting and more generally in printing, photography and cinematography (CMY) which, by filtering white light as described above, allow the three additive colors RGB to be obtained as the result of light subtraction by absorption.

## 2. Research hypothesis

In this context, we carried out an empirical research aimed at detecting possible misconceptions about color held by primary school pupils and teachers. The hypothesis of the research is that some misconceptions are linked to the lack of explicit distinction between physics, physiology of

the visual system and painters' practice standpoint, respectively. We also believe that these misconceptions are relatively independent of the subjects' level of education (children/teachers).

In particular, we expected to detect the following children's misconceptions:

- (1) the belief that color is an intrinsic property of objects and the confusion between light colors and pigment colors (QC1, QC2). These misconceptions are well known in scientific literature (see note 3) (e.g. Hawkins 1985, Anderson and Smith 1986; La Rosa and Meyer 1991; Feher, E. and Meyer, K. R. 1992; Haagen, C. 2014);
- (2) difficulty in distinguishing between mixing of pigments and mixing of lights (QC3, QC4, QC5);
- (3) the knowledge of primary colors limited to the painters' practice standpoint taught in arts education (QC4);
- (4) the merely superficial knowledge of the physical interpretation of color (QC6).

As for teachers' misconceptions, we expected to detect:

- (1) poor knowledge of the scientific interpretation of the color vision phenomenon (QT1, QT2);
- (2) knowledge of primary colors only as pigment colors out of which all the others can be made (QT3, QT4);
- (3) inability to distinguish between "almost pure colors" (characterized by a dominant wavelength and a narrow band) and colors produced by the addition of lights (QT5, QT6, QT8);
- (4) confusion between the mixture of pigments and that of colored lights (i.e. between additive and subtractive synthesis). In particular, our hypothesis is that the colored light is mixed with the "color of the object", as expected from the pigment mixing model. This implies teachers hold the (more or less implicit) belief that color is a quality of objects independent of both the type of light source that illuminates the object and the characteristics of human vision (see note 3) (QT7, QT9).

## 3. Methodology and tools

The research was conducted by administering two different self-completed questionnaires (Corbetta 2003, p. 179) allowing subjects to answer questions independently, without the need for an interviewer to be present. The two questionnaires were addressed to primary school teachers and to fifth-grade pupils, respectively, according to a non-probabilistic sampling of convenience.

The sample consisted of:



- 30 primary school teachers from the Province of Pesaro-Urbino.
- 92 fifth-grade pupils. In particular, 18 children attending the school complex in Cattolica (Rn), 11 attending the school complex Binotti in Pergola (PU), 22 attending the school complex Olivieri in Pesaro (PU), 21 attending the school complex Pascoli in Urbino (PU) and 20 attending the school complex Villa San Martino (PU).

Data from the two groups were collected as follows: teachers answered the questionnaire under the guidance of an Internship Tutor from "Education Sciences for Nursery and Primary School" at Urbino University, who had previously been "trained" by the authors of this article. The children were informed in advance about the purpose of the investigation and assisted in filling in the questionnaire by their own teachers, who were given precise instructions to carry out a data collection as error-free as possible.

#### 4. Children's misconceptions research results

Below we provide the children's answers to the questionnaire (QC), organized according to response types gained from the reading of the data.

<b>QC1. What is color for you?</b>		
Color is linked to emotions	32	35%
An object property/A tool that colors things	13	14%
Color is a light/colored light	11	12%
Paint/colored spot/colored substance	11	12%
Tautological answers: e.g., "color is a colored form"	5	5%
Answers that identify a function of the color: "the color is needed to ..."	3	3%
Don't know	3	3%
Not relevant	2	2%
Other	12	13%
<b>QC2. Why do we see objects of different colors?</b>		
Because everything has its color	20	22%
By means of light/sun	16	17%
Because of emotional reasons	14	15%
Because they are painted	13	14%
Because our eyes can do it	12	13%
In order to distinguish them	8	9%
Don't know	5	6%
Other	4	5%

The first two questions were aimed at detecting children's naive conceptions about color. First, a marked variety of response types (especially regarding the first question) may easily be noted. Among the answers the most common (35% for the first question and 14% for the second question) were those that interpret color as a

source of feelings and emotions: "color is a source of joy". The idea of color as an intrinsic quality/property of objects is widespread as well (14% for the first question and 22% for the second): "because everything has its color"; "Because God wanted so". This naive idea is implied, more or less implicitly, also by the answers (about 14% of the total) according to which we see objects of different colors because they have been painted/colored. The concept of color as light occurs in 12% of responses to the first question and in 17% of responses to the second question. The answers, however, highlight naive conceptions: "color is a light that colors things"; "Color is a colored light"; "We see objects of different colors because the light 'touches' an object and gives it color".

Questions QC3, QC4 and QC5 have been proposed to detect children's misconceptions related to the analogy between light mixing and pigment mixing.

<b>QC3. Is it possible to get a black light by mixing colored lights?</b>		
Yes	55	60%
No	35	38%
Don't know	1	
Don't answer	1	
<b>QC4. What are primary colors? What primary colors do you know?</b>		
They are those colors that allow to produce all the others/Those which cannot be derived from any others	27	29%
Don't know	17	18%
They provide only color occurrences	14	15%
They are the most used colors	7	8%
They are the lightest colors	6	7%
They are the ones that come first	5	5%
They are the "prime" colors	2	2%
Other	14	15%
<b>Among children who claim to know primary colors:</b>		
They mention the triad red-green-blue	2	2% <sup>c</sup>
They mention the triad red-yellow-blue	19	21%
They provide incorrect examples of colors	50	54%
<b>QC5. Let's imagine putting a very big traffic light in the classroom and turning off the light. When the red light comes on, what color does the blue chair appear to be?</b>		
Violet	38	41%
Red/Red and blue	8	9%
Black	7	8%
Brown/orange	7	8%
Green	6	7%
Yellow	4	4%
Blue	3	3%
Don't know	6	7%
Don't answer	4	4%
Other	9	10%

Regarding question QC4, children respond adequately in 29% of cases. The reason may lie in the fact that the answer corresponds to a traditional teaching content. As we will see later, this datum is confirmed by the answers provided by the teachers. However, this does not mean that the underlying conception is fully correct. As a matter of fact, even when children provide a plausible explanation of what primary colors are, they identify incorrect colors. Another interesting result concerns the triads mentioned: red-green-blue (2%) and red-yellow-blue (21%). They identified two distinct categories of primaries, the first referring to the additive synthesis of lights, while the second to the subtractive mixture of pigments. However, the occurrence of these two triads in children's responses is not justified on the basis of this distinction.

The fifth question (QC5) was intended to ascertain the confusion between the mixture of pigments and that of colored lights. Evidence in favor of this hypothesis comes from 41% of the responses, where children state that in the described circumstances they chair would appear violet, exactly as would result by overlapping the red of the light and the blue color of the chair. Further evidence is provided by the high percentage of affirmative responses (60%) to QC3, showing that the pigment mixture model is used even when lights rather than pigments are mixed.

The responses to the last question (QC6) are displayed in table below. The answers show that 10 children refer to the scientific phenomenon of light decomposition: 4 explicitly allude to the visible spectrum and 6 allude to the phenomenon of decomposition. However, even in this case, their responses reveal a merely superficial knowledge. "Inside the prism, the white light reflects to the glass and so gives rise to the visible spectrum"; "Passing through the prism, white light splits into the visible spectrum". Some children (9) answer that they have already heard of Newton's prism, which is, indeed, a traditional learning content taught at school.

QC6. Do you know Newton's prism?		
They say they don't know Newton's prism	24	26%
They claim to know Newton's prism	9	10%
Don't answer	59	64%
Can you tell what happens to white light when it passes through the prism?		
The light becomes colored / turns into a rainbow	33	36%
I don't know	16	17%
Light splits into colors	6	7%
The visible spectrum is formed	4	4%
They describe different phenomena	21	23%
Other	12	13%

Our supposing that children fail to show a meaningful understanding of the scientific phenomenon is supported by the fact that if we compare these answers with those given by the same children to the previous questions, internal inconsistencies emerge. For example, with

reference to the first of the responses cited above – "Inside the prism, the white light reflects to the glass and so gives rise to the visible spectrum" –, the same pupil to the question "What is color" (QC1) answers: "An ink that paints things".

## 5. Teachers's misconceptions research results

We provide the results of the teachers' questionnaire (QT) without specifying the percentage data because of the narrowness of the sample.

As regards the first question (QT1) – "Why do we see objects of different colors?" (A question corresponding to QC2 of the children's questionnaire) – most teachers (21 out of 30) make a general reference to light absorption and reflection phenomena. Deep knowledge gaps emerge from 7 answers. In just 2 cases, teachers offer more precise responses including each of the three elements involved in color vision (light source, human eye, objects absorbing and reflecting wavelengths of light). For example: "because our eye has the ability to see the colors of light reflected by various objects". If asked about the nature of black and white – "How can black and white be defined with reference to what is represented by figure 1?" (QT2) – two teachers provide correct definitions: in one case, White = light, black = absence of light; in the other, white is the mixture of all colors, black is the absence of light and thus of color. Many recognize black and white as non-colors but providing incorrect justifications or not providing any. In 7 other cases the teachers refer to white and black as colors of objects.

Concerning questions QT3 and QT4 aimed at investigating naive ideas about primary colors (see figures 2 and 3), most answers show they are mainly defined as the colors from which all the others derive.



Fig. 1. Prismatic decomposition of light

There is no clear awareness about the difference between light colors and pigment colors, however. Except for two cases, teachers, indeed, do not distinguish between additive and subtractive primaries. Moreover, similarly to what emerges from children's responses, the

predominantly cited primaries are the traditional painters' ones (red, yellow and blue), as a further proof of the dominance of the pigment mixing model.

The question QT5 asks if "two perceptually identical colors can be different from a physical standpoint". Teachers respond "yes" in 23 cases out of 30. However, if we compare these answers with those given to questions QT6 and QT8, it is hard to suppose they really understand the difference. When asked the reason why a lemon appears yellow (QT6), only 2 teachers are aware of the double possibility that the lemon reflects the wavelength corresponding to yellow light or the wavelengths corresponding to red and green lights (proving to interpret yellow as a result of the additive synthesis of these two light colors). Moreover, considering question QT8 – "Is there a difference from a physical standpoint between the yellow color in Figure 1 and the yellow color in Figure 2? If yes why?" – which actually provides an exemplification of question QT5, only 9 teachers answer yes and, among these, only 2 partially justify their choice.

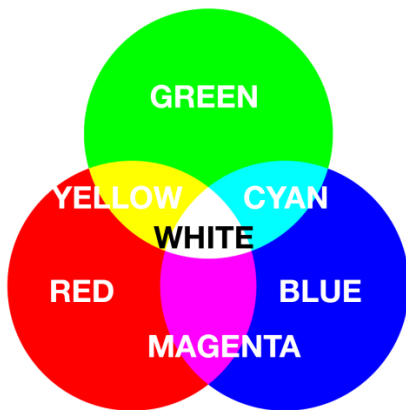


Fig. 2. Additive color mixing

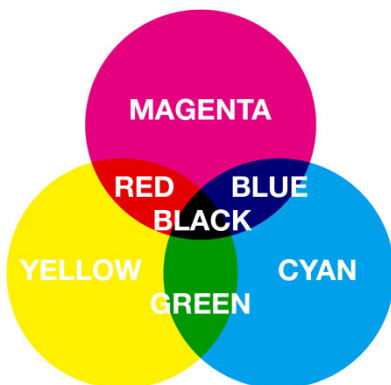


Fig. 3. Subtractive color mixing

Regarding question QT7 – "If an object illuminated by sunlight appear blue, what color will it appear to be if illuminated by a light source emitting only red-light beams?" –, 11 teachers answer the object will appear violet. Among the others, 6 teachers opt for black, 4 for blue, 2 for green, 1 for brown and 1 for pink, respectively.

Finally, 3 teachers admit not to knowing the answer and 1 does not respond. It is noted that also in this case, as in the case of question QC5 addressed to children, most responses converge on the same choice that is violet. This confirms that the dominance of the pigment mixing model is relatively independent of the level of schooling attained.

Our hypothesis is further corroborated by the answers to the last question QT9 – "How will appear a magenta colored object that absorbs the wavelengths corresponding to the green, if illuminated with monochromatic radiation, i.e., light of a single color such as red, blue or green respectively? And finally, how will it appear in sunlight?" –, most of which are null (they do not know or do not answer) or irrelevant. In 4 cases, teachers' predictions highlight the pigment mixture model underlying their reasoning. For example: "(...) If the magenta object were illuminated by green light, we should see it black because magenta is made up of red and blue, so, adding green light, we would obtain the triad that produces the black color (...)".

## 6. Discussion and conclusive remarks

As regards the hypotheses formulated in section 2, the following conclusions can be advanced for the research carried out on children and teachers respectively.

- (1) The conception of color as an intrinsic property of objects emerges both explicitly from some responses and implicitly, as a presupposition underlying other misconceptions.
- (2) The confusion between light and pigment colors is highlighted by the high response rate to question QC3. This tendency is confirmed by the evident lack of distinction between additive and subtractive primaries as shown in QC4, as well as by the dominance of the pigment mixing model in QC5, where reference is made to the overlap between the red light and the blue color of the chair (conceived as an intrinsic quality of the object).
- (3) Unlike what was hypothesized, not all children in our sample know primary colors. Some of them provide interpretations partially relevant, while others make references to other fields of experience. Those who show to have some, albeit superficial, knowledge of primary colors confirm that it is circumscribed to the painters' triad (red, yellow, blue), probably acquired during school arts activities.
- (4) A small minority of children refers to the spectral decomposition of light passing through a prism. However, we assume that theirs is a merely superficial knowledge due to the lack of consistency

with the answers previously given, which point out the persistence of the misconceptions highlighted above.

As regards the hypotheses formulated about the teachers, the following conclusions are advanced.

- (1) The scientific mastery of the color vision process is somewhat partial. Teachers, indeed, refer to the three basic elements of color vision (light source, human eye, objects absorbing and reflecting wavelengths of light) in only two cases. This is also confirmed by the limited relevance of the responses to the second question, i.e. about the definition of white and black with reference to the prismatic decomposition of light.
- (2) The knowledge of primary colors is almost exclusively limited to their interpretation as the basic pigment colors whose mixture produces all the others. As a matter of fact, teachers mainly mention the painters' triad red-yellow-blue, showing no awareness of the difference between additive and subtractive primaries.
- (3) Teachers confuse physical and physiological aspects of color vision since they do not distinguish between spectral monochromatic colors (colors with single wavelengths) and non-spectral colors that can be obtained as a result by adding lights of different wavelengths. Although in some cases non-spectral colors are perceptually identical to monochromatic colors, they are different from a physical standpoint, however.
- (4) The hypothesis of the misleading analogy between the mixing of lights and the mixing of pigments (i.e., between additive and subtractive synthesis) is confirmed. Similar to what was observed with children, many teachers tend to mix the color of the light illuminating the object with the color of the object considered as its intrinsic property.

From what is outlined above, the following conclusion can be drawn: both teachers and students show misconceptions and naïve ideas about color vision due to the lack of explicit distinction between physics, physiology of the visual system and painters' practice standpoint, respectively. More, this confirms that the misconceptions highlighted in this paper are relatively independent of people's level of education; on the other hand, it points out the necessity to make these three different perspectives explicit in teaching and learning process, in order to foster a meaningful knowledge about color.

## 7. Conflict of interest declaration

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

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## Notes

[1] The paper was written by the authors jointly. Specifically, B. Martini wrote sections 4 and 6; M. Tombolato wrote sections 1 and 5; R. D'Ugo wrote sections 2 and 3.

[2] In this context, assuming intentionality as a structural feature of knowledge means highlighting the "perspectival character" of scientific knowledge. As suggests the philosopher of science Evandro Agazzi (2014, p. 83), different disciplines investigate 'things' from different perspectives. The same 'thing' can thus become the object of a variety of sciences when considered from different standpoints.

[3] From a didactic standpoint, this means that the color of an object is conceived as being independent of both the type of light source that illuminates the object and the characteristics of human vision. Making the example of a person looking at a colored object in white light, Anderson and Smith (1986) highlight two different interpretations capable of explaining the observed phenomenon:

"1. A scientific interpretation: White light is a mixture of colors of light. Objects absorb some of those colors of light and reflect others, and people see the colors of the reflected light.

2. A naive interpretation: White light is clear or colorless. It brightens objects and in so doing reveals their colors, which are innate properties of the objects themselves. People's eyes see the colors of the objects".

As Haagen (2014) points out: "One prerequisite for understanding optics, including color phenomena, on a basic level is the idea that objects which do not produce light themselves are able to absorb and reemit light. Only when light (re)emitted by an object enters the eye of an observer, he or she can perceive the object. This sender-receiver mechanism also determines the kind of color we see, as the color depends on the kind of light we receive. Consequently, without this basic concept of a sender - selective (re)emission - receiver model, it seems to be difficult to develop scientifically adequate ideas concerning color and colored objects".

[4] On the distinction between 'obstacle' and 'mistake' from an educational standpoint, see Martini 2000, pp. 89-102.

[5] Consider, for example, Galileo's approach to science based on the use of idealized models and thought experiments in order to interpret natural world phenomena. (McMullin 1985). Both idealized models and thought experiments are used in teaching about color and color vision, at least on a basic level.

[6] Numerous experiments showed that if two primary color lights (for example, red and green) are combined, new colors are obtained. On the contrary, by mixing the two corresponding pigment colors only dirty grays are obtained (De Grandis 2000, p. 17).

## References

- Agazzi, E. (2014) *Scientific Objectivity and Its Contexts*. Heidelberg/New York/Dordrecht/London: Springer.
- Anderson, C. W. and Smith, E. L. (1986) 'Children's Conceptions of Light and Color: Understanding the Role of Unseen Rays'. Michigan: The Institute for Research on Teaching. Available at: <https://eric.ed.gov/?id=ED270318>. (Accessed: 27 March 2019).
- Bachelard, G. (2002) *The formation of the scientific mind*. Manchester: Clinamen.
- Brousseau, G. (1983) 'Les obstacles épistémologiques et les problèmes en mathématiques', *Recherches en didactique des mathématiques*, 4(3), pp. 165-198.
- Corbetta, P. (2003) *La ricerca sociale: metodologia e tecniche. Le tecniche quantitative*. Bologna: Il Mulino, vol. II.
- De Grandis, L. (2000) *Teoria e uso del colore*. Milano: Mondadori.
- Feher, E. and Meyer, K. R. (1992) 'Children's conceptions of color', *Journal of Research in Science Teaching*, 29(5), pp. 505-520.
- Gardner, H. (2004) *The unschooled mind: how children think and how schools should teach*. New York: Basic Books.
- Giudice, F. (2009) *Lo spettro di Newton*. Roma: Donzelli.
- Haagen, C. (2014) 'Simple experiments supporting conceptual understanding of body colour', *Pridobljeno*, 12(4), 2017.
- Hawkins, D. (1985) 'Barriere critiche alla comprensione delle scienze', in Cortini, G. (eds) *Le trame concettuali delle discipline scientifiche. Problemi dell'insegnamento scientifico*. Firenze: La Nuova Italia, pp. 127-143.
- La Rosa, C. and Mayer, M. (1991) 'Luce e colori', in Grimellini Tomasini, N. and Segrè, G. (eds) *Conoscenze scientifiche: le rappresentazioni mentali degli studenti*. Firenze: La Nuova Italia, pp. 185-229.
- Martini, B. (2000) *Didattiche disciplinari. Aspetti teorici e metodologici*. Bologna: Pitagora.
- Martini, B. (2018) 'La dialettica sapere formale/sapere della pratica alla luce della dialettica sapere/sapere da insegnare', *METIS. Mondi Educativi*, 8(2), pp. 50-67.
- Mason, L. (2006) *Psicologia dell'apprendimento e dell'istruzione*. Bologna: Il Mulino.
- Martinez-Borreguero, G., Pérez-Rodríguez, Á. L., Suero-López, M. I. and Pardo-Fernández, P. J. (2013) 'Detection of misconceptions about colour and an experimentally tested proposal to combat them', *International Journal of Science Education*, 35(8), pp. 1299-1324.
- McMullin, E. (1985). 'Galilean idealization', *Studies in History and Philosophy of Science, Part A*, 16(3), 247-273.
- Morin, E. (1999) *La tête bien faite: repenser la réforme, réformer la pensée*. Paris: Éditions du Seuil.
- Newton, I. (1671–72). 'New theory about light and colors', *Philosophical Transactions of the Royal Society*, 80, pp. 3075–3087. Available at: <http://www.newtonproject.ox.ac.uk/view/texts/diplomatic/NATP00006>. (Accessed: 22 March 2019).
- Piana, G. (2000) 'L'esperienza della transizione e il sistema dei colori'. *Archivio di Giovanni Piana*. Available at: <http://filosofia.dipafilo.unimi.it/~piana/index.php/filosofia-dellesperienza>. (Accessed: 22 March 2019).
- Şahin, Ç., İpek, H. and Ayas, A. (2008) 'Students' understanding of light concepts primary school: A cross-age study', *Asia-Pacific Forum on Science learning and teaching*, 9(1), pp. 1-19.
- Shapiro, A. E. (1994) 'Artists' Colors and Newton's Colors', *Isis*, 85(4), pp. 600-630.
- Strike, K. A. and Posner, G. J. (1992) 'A revisionist theory of conceptual change', in Duschl, R. and Hamilton, R. (eds) *Philosophy of science, cognitive psychology, and educational theory and practice*. Albany, NY: SUNY Press, pp. 147-176.
- Tombolato, M. (2018) 'La dialettica generale/specifico alla luce del costruito didattico di ostacolo epistemologico', *Formazione & Insegnamento. Rivista internazionale di Scienze dell'educazione e della formazione*, 16(2), Supplemento, pp. 205-214.
- Vosniadou, S. (2003) 'Exploring the relationships between conceptual change and intentional learning', in Sinatra, G. M. and Pintrich, P. R. (eds) *Intentional conceptual change*. London: LEA, pp. 377-406.

# Chromatic values in Pablo Picasso's early work: a comparison of hues in "Science and Charity" (1897) and its three oil sketches

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## ABSTRACT

This paper deals with the chromatic and colorimetric analysis of one of the most representative paintings by Pablo Picasso (1881-1973) of his formative years, "Science and Charity" (*Ciencia y Caridad*, 1897), and its three oil sketches of the Museu Picasso in Barcelona. Picasso, among the modern painters, turned from a subdued chromatism to brilliantly varied palettes in the course of his career. 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. This study was carried out in the framework of an inter-institutional research project aimed to gain an insight into the failure mechanisms of modern and contemporary paintings.

**KEYWORDS** Pablo Picasso, painting *Ciencia y Caridad*, conservators' colour perception, FORS, colorimetric measurements, hyperspectral imaging

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## 1. Introduction

Pablo Picasso, who since the start of his career was supported by his father José Ruiz Blasco, also a painter, obtained his first success in Barcelona where his painting "Science and Charity" (*Ciencia y Caridad*, 1897, size 197.0 cm x 249.5 cm, inv. number MPB110.046) gained recognition also in a national competition. Subsequently, the painting has been acknowledged as one of the most representative works of Picasso's formative years and it is one of his significant paintings belonging to the permanent collection of Museu Picasso in Barcelona (MPB), where it has recently been restored. This oil painting on canvas depicting a bedridden woman reveals the artist's early interest in fin-de-siècle art which was drawn to such topics as physical illness, madness, and decadence. It marks his accomplishment in academic art education in turn-of-the-twentieth-century Spain. Moreover, Picasso was one of the modern painters who in the course of his career turned from a subdued chromatism to variegated palettes of brilliant hues (Gage 2006). This paper will discuss one of his most important paintings hosted at MPB, namely, the already mentioned "Science and Charity", and three smaller oil paintings on different supports (1896-97), all of which are displayed next to the big canvas and are considered to be its preparatory sketches. These sketches reveal a different organization of the scene presented in the larger version as well as differences in the hues the artist used in portraying the same characters and objects that appear in the scene.

The present study was carried out in the framework of an inter-institutional research project (ProMeSA) whose aim was to gain knowledge of the failure mechanisms of modern and contemporary paintings that produce degradation patterns in their paint layers (Fuster-Lopez et al. 2018). Within the ProMeSA project, the study of the materials and techniques used by the artist, in particular the chromatic and colorimetric analysis of Picasso's (1881-1973) paintings at the MPB, involved several different documentation and analytical methodologies. "Colour," as Gage points out at the beginning of the introduction of his book "Color in Art", "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 ..." (Gage 2006). Moreover, he continues, "colour is primarily a psychological phenomenon." Indeed, although the link between various colours as a psychological phenomenon and the way artists apply their creativity to experimenting with colour has already been explored by art historians, critics, and artists themselves (Buswell 1935, Arnheim 1974, Gombrich 1968, Gage 1999), the reflections expressed in their publications often do not stem from or

take into consideration scientific data and measurements. Hence, the present study proposes a relatively new method in gaining insight into artworks by merging the visual approach employed by professionals, such as painting conservators, who have expertise in the field, with scientific measurements of colorimetric values calculated from the reflectance spectra of the specific investigated spots (Parraman 2010, Striova et al. 2018, Dooley et al. 2014).

This study started with a visual investigation of the various colours the young Picasso used in the four paintings to stylistically structure them; subsequently, ten spots (areas with a diameter of 3 mm) were selected on the same zones of each painting to be measured by using a spectroradiometer (Figs. 1-4). The aim was to discover if there were any associations in the painted scenes – in the painting and the three oil sketches—between the measured colorimetric values, the chromatic painting balance, and the colour perception of MPB conservators so as to gain an enhanced understanding of the conditions of these artworks.



Fig. 1. Painting "Science and Charity" (MPB 110046) with the investigated spots.

## 2. "Science and Charity" painting and its sketches

At the end of 1896 and beginning of 1897, Picasso worked on the painting "Science and Charity" (Fig. 1). It was the most ambitious early work by the young artist (Gual and Jiménez 2010, Jiménez 2018). The choice of the topic was not unintentional; the human condition and illness had intrigued him since the death of his sister Conchita (who passed away in January 1895), but he was also fascinated by real life and social issues that he foregrounded in the scene. Indeed, with this painting, Picasso connected with

the Social Realism movement, whose popularity at the time was at its peak in all of Europe. The origin of the so-called 'hospital theme' addressed in the painting can in Spanish art be traced to 1889 when Luis Jiménez Aranda won the gold medal at the Spanish Pavilion at the Universal exhibition in Paris with his painting "The Doctor's Visit"; it was one among other artworks that depicted similar subjects.

In May 1897, this large oil painting on canvas was exhibited at the 16th Fine Arts General Exhibition in Madrid, where it was also awarded. Some months later, it was sent to Málaga to the Provincial Exposition. The painting then remained in Málaga at the house of Picasso's uncle, Salvador Ruiz. It was kept there until the uncle's death in 1918, after which it was brought back to Barcelona. Since then, this impressive canvas was hanging in the Picasso family house located in Barcelona. It was only in May 1970 that the artist decided to donate it to the MPB so that it could be integrated into its permanent collection. During the same year, the painting was treated in the conservation studio of the Museu de Barcelona at the Museu Nacional d'Art de Catalunya (MNAC) in Barcelona. The conservation work included relining the fabric and mounting it on a new stretcher, retouching the paint losses, and varnishing the painting. Since then, it has been displayed in the museum galleries. It was loaned out only in 1980, to participate in a Picasso exhibition organized at the Museum of Modern Art (MOMA) in New York.

In addition to the early conservation work, scientific analyses were performed on "Science and Charity" for the first time in 2008. These included X-ray radiography, which assessed the condition of the original fabric and contributed to the study of the artist's technique. In addition, several micro-samples were taken in order to determine the cross-section of the painting materials. The results of these scientific analysis were presented within the context of an exhibition entitled *Ciencia y caridad al descubierto* and were subsequently published in the exhibition catalogue (Gual and Jiménez 2010, Jiménez 2018). These were the first scientific studies that contributed to the understanding of the pictorial technique, while also enabling an enhanced documentation of Picasso's working process. For instance, the X-ray radiography revealed that the artist had worked in multiple sessions during which he made several modifications to the composition. In some areas of the painting, for example in the blanket covering the ailing woman, as many as seven successive colour applications were observed and, moreover, it was discovered that in most cases the subsequent paint layers had been applied only after the previous layer had completely dried.

Another significant discovery concerned the correspondences that now could be demonstrated between "Science and Charity" and other works of smaller format: six from MPB and other three belonging to other collectors. These small paintings, which until 2008 were thought to be preparatory sketches, were instead revealed to be key-documents that played an important role in the artist's creative process during the execution of "Science and Charity". They allowed not only the preparation of a chronological sequence (table 1), but also helped illustrate in a visual way the different phases of the painting process of "Science and Charity" since each of them represents a transition to the subsequent stage until the completion of the final version. Thus, together the paintings form an invaluable documentary set.

When compared to the final version, the noteworthy alterations in the smaller paintings, together with compositional changes and modifications concerning light and colour demonstrate the young artist's efforts in ameliorating the narrative realism and pictorial composition of the painting.

Artwork	Technique	Place and date	Size (cm)
MPB 110387	Charcoal on paper	Barcelona, 1896	10.5 x 27.7
MPB 70802R	Charcoal and Conté pencil on paper	Barcelona, 1896-97	28.0 x 47.5
MP 409(r) Zervós XXI, sheet 46 [10]	Brown ink, watercolor enhancements and violet ink on paper	Barcelona, 1896	16.5 x 22.2
<b>MPB 110099</b>	Oil on canvas	Barcelona, 1897	23.8 x 26.0
MPB 110089	Watercolor on paper	Barcelona, 1897	22.5 x 28.6
<b>MPB 110229</b>	Oil on panel	Barcelona, 1897, dated on the reverse March 1897	19.5 x 27.2
Zervós, VI, sheet 46 [10]	Watercolor, ink and pencil on paper	Barcelona, 1896-97	37.0 x 25.5
<b>MPB 110214</b>	Oil on panel	Barcelona, 1897	13.6 x 22.4
<b>MPB 110046</b>	Oil on canvas	Barcelona, 1897	197.0 x 249.5
Zervós, I sheet 10 [10]	Oil on canvas	Barcelona, 1897	38.0 x 48.0

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).

### 3. Considerations about the investigated sketches

The four oil paintings belonging to MPB (MPB 110046, 099, 214, and 229, see table 1) were studied within the ProMeSA project so as to establish their different physicochemical correlations that would help to gain a



better understanding of the condition of the painting. In 2018, these four paintings were analysed by using the following spectroscopic techniques: visible (Vis) and near infrared (NIR) fibre optic reflectance spectroscopy (FORS), in the 350-2200 nm range, on different spots on the painting surfaces; reflectance hyperspectral imaging (HSI) in the 400-900 nm (VNIR) and 950-1650 nm (SWIR) ranges (HSI on the painting Science and Charity, MPB 110046, was acquired only in the SWIR region). Furthermore, measurements focused on the colorimetric data on 10 selected spots were also recorded by using a Konica-Minolta CM700d spectrophotometer (Konica Minolta 2008). In addition, in 2010 a set of micro-samples taken only from the painting "Science and Charity" (MPB 110046) had already been analysed by using scanning electron microscope (SEM) and Fourier transform infrared (FT-IR) techniques. In this paper, however, it was decided to report the colorimetric data only.



Fig. 2. Painting MPB 110099 with the investigated spots.

The first small painting analysed was the MPB 110099 (Fig. 2), which is a rapidly made sketch on a piece of cloth revealing certain clumsiness, which makes it probable that Picasso abandoned it, also because it does not have any resemblance to the final version.

The second preparatory oil painting MPB 110229 (Fig. 3), which the artist dated on the verso of the panel (March 1897), presents a structure that appears more similar to the final version. Here the nun, in the centre of the scene right next to the main characters, is standing close to the bed holding a cup in her right hand and a child on her left arm. In this version, the child is naked and looks younger than in the final painting. In addition, the sick woman here is not looking toward the doctor, and her right arm is placed on the bed, while the doctor is depicted holding her hand.

The main character of the composition, the doctor, is here not seen in profile but portrayed in a three-quarter view like in the final big canvas painting. However, there is still a big difference between this and the final version: here, like in the first sketches, including the watercolour (MPB 110089), the doctor's hair is white. In addition, the window is positioned on the right section of the scene.



Fig. 3. Painting MPB 110229 with the investigated spots.

This work maintains the luminosity of the previous version evident in the great brightness and palette that abounds in white, grey and ochre. The only dark colours, which persist throughout the execution process, are the black of the doctor's frock coat and dark blue of the nun's dress. In this particular oil sketch, as discovered in an image extracted at 1300 nm (IR reflectography) from the SWIR HSI data, Picasso made an attempt to seat the doctor in a rocking chair, whose skates he subsequently covered with light paint, turning the seat into a chair. This detail does not lead to Picasso's final version either because the final painting shows a rectilinear structure of the legs of the chair.

In the painting MPB 110214 (Fig. 4) the artist decided on a radical change that brought him closer to the final painting. He dressed the child in a red suit and rectified his position by placing him higher within the composition. In this way, the child is slightly separated from the mother and physically closer to the nun, who has also turned to a three-quarter position. The figure of the doctor is already resembling the physiognomy of Picasso's father, Don José. The figures in this sketch all have a certain disproportion to the general format of the board support, which seems to indicate that it is a sketch quickly prepared with the purpose of studying the chromatic and tonal effect without altering the basic composition. In this sketch, and by extension in this phase of the creative process, the palette changes completely. It seems that Picasso gradually darkened the composition, throwing shadows over the scene: he seems to have decided to cover the white sheet with a rough ochre blanket, to apply a dark

brown coat on the light grey background around the doctor, and literally to close the window by masking the white appearing in the preparatory versions with a very thin brown coat.

It seems that from this moment, the painting has obtained its final version, with the exception of the frame in the centre of the wall, which, however, appeared in the Zervos version. This fact suggests that Zervos is the last sketch Picasso worked on before completing his final version of "Science and Charity" (Zervos 2013).

#### 4. Colorimetric data

The analytical results reveal that despite the dissimilarities in the structure and composition of the four oil paintings (including furniture, position of characters, etc.), the artist used similar painting materials (i.e. pigments) in all four versions. This knowledge facilitated the selection of ten spots on each artwork; these were the most representative hues and details apparent in the final painting. After careful consideration, it was decided to analyse the following

spots (Figs.1-4): 1) on the wall in the background in the centre of the scene; 2) the brownish window curtain/shutter; 3) the sick woman's face; 4) the doctor's face; 5) the nun's face; 6) the white bed sheet; 7) the right sleeve of the doctor's jacket; 8) the blanket or the sheet at the end of the bed; 9) the nun's dress; 10) the child's dress.

Since the child was missing from the scene of the first sketch (MPB 110099), spot n.10 was not included.

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 (Konica Minolta 2008). 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) (Wyszecki and Stiles 1982, CIE 1982, ISO/CIE 10526 and 10527 1991).



Fig. 4. Painting MPB 110214 with the investigated spots.

	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.



	MPB 110229				MPB 110229				MPB 110214			
	L*	a*	b*	$\Delta C^*$	$\Delta L^*$	$\Delta a^*$	$\Delta b^*$	$\Delta C^*$	$\Delta L^*$	$\Delta a^*$	$\Delta b^*$	$\Delta C^*$
1	0.9	2.6	-0.5	-0.8	-0.2	1.1	9.3	8.9	3	1.2	2.6	2.0
2	22.1	-2	8.3	6.4	23.9	-1.6	18.4	16.4	2.8	-1.8	-2.1	-2.7
3	-2.2	-1.2	-3.9	-4.1	-16.5	-2.1	-7.3	-7.7	-14.2	-1.9	-8.7	-8.8
4	12.6	-2.2	-0.2	-1.4	-8.5	-6.3	0.6	-1.9	-9.5	-6.5	-7.1	-9.5
5	6.4	-2.4	-8.4	-8.6	-9	5.5	-1.4	1.6	-9.2	-2.3	-6.5	-6.9
6	-6	-1.9	-2.3	-2.5	-19.7	4.8	7.2	8.3	-20.9	1.9	-4	-3.1
7	14.4	0.4	3.4	0.6	-0.8	0.9	4.6	1.8	-1.7	-0.1	0.9	-0.8
8	8.4	-4.5	-10.4	-11.1	5.1	-3.1	-3.7	-4.3	2	0.5	0.6	0.7
9	7.2	0.3	1.5	-0.8	8.9	-2.8	1.7	1.8	1.4	0.1	1.2	-1.1
10					-13.3	8.5	3.1	7.4	-11.9	7.6	1.2	5.5

Tab. 3 –  $L^*a^*b^*$  and  $C^*$  ( $10^\circ/D65$ ) differences of the three sketches considering the final painting (MPB 110046) as reference.

The 'atmosphere' of the scene is most strongly conveyed through the hue used to paint the walls of the room. The data obtained from the four paintings showed no noticeable discrepancies: an inhomogeneous medium-light grey 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.



Fig. 5. Acquisition of colour measurements on the Science and Charity painting, final version.

The second spot, instead, shows a strong variation in hue passing from one sketch to the others and it turns into a saturated, dark brown in the final version. It is important to note, however, that the resulted colour is more neutral in the last two paintings, with a slight red and yellow presence, than in the first two sketches where the yellow tint is more dominant (Fig. 6).

The complexion in the faces of the three adult figures varies not only between the paintings but also within each painting. This seems to confirm the hypothesis that the first three paintings were preparatory sketches in which the artist found no necessity to refine the faces. Moreover, Picasso used the colour of each character's complexion to indicate their healthy or sickly condition.

The measurements confirmed that the sheet on the bed was whitish with some chromatic dominant turned into yellow. Only in the third sketch the white results more neutral with almost the same values of both yellow and red contributions.

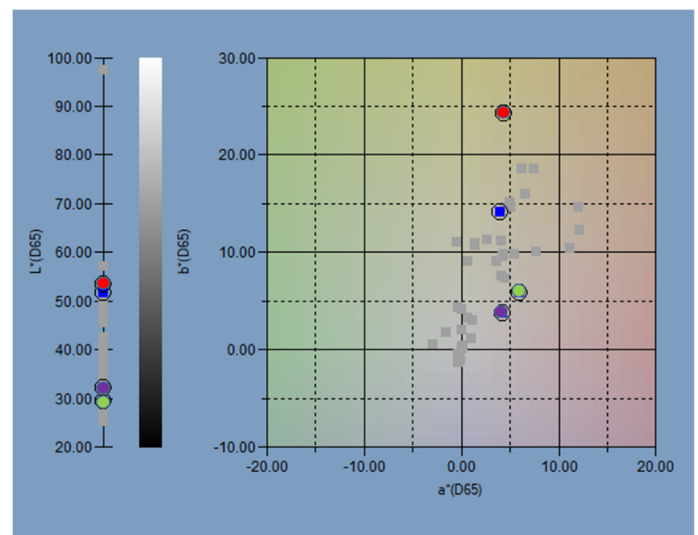


Fig. 6.  $L^*a^*b^*$  ( $10^\circ/D65$ ) colour graph of the investigated 2<sup>nd</sup> spot for the four paintings: MPB 110046 (green), MPB 110099 (blue), MPB 110214 (red), and MPB 110229 (purple).

The blanket on the bed is included in the scene only starting from the last sketch. However, the colorimetric values do not reveal any significant differences moving from the sketch to the last version, the final painting. In the first two works, the blanket blends in with the sheet, of a creamy hue, which, in the later versions, is not so different from the yellowish-brown final hue (Fig. 7).

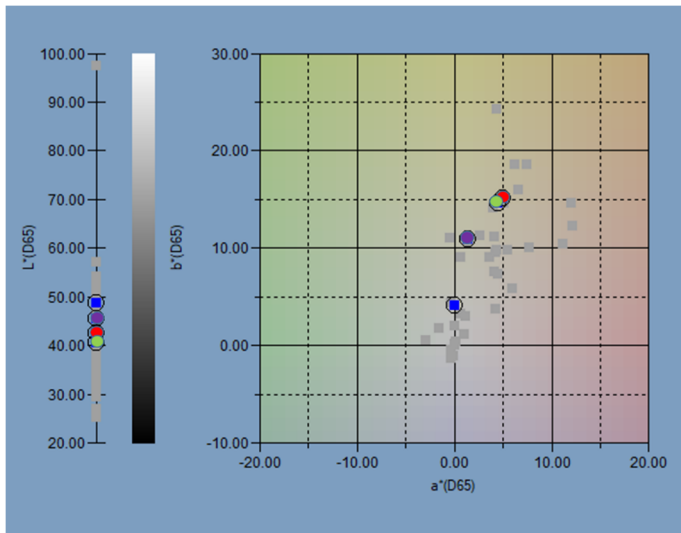


Fig. 7.  $L^*a^*b^*$  ( $10^\circ/D65$ ) colour graph of the investigated 8<sup>th</sup> spot for the four paintings: MPB 110046 (green), MPB 110099 (blue), MPB 110214 (red), and MPB 110229 (purple).

The hue of the doctor's bluish dark jacket remains more or less constant throughout the genesis of this artwork.

The nun's dress is almost black in all versions except in the second one in which it is depicted as a bluish dark tone.

The final spot, the child, appears in three different situations: the naked child, a child with orange-red cloth, and finally a child wearing a reddish-lily shirt. However, the colorimetric parameters for the first two variations of the naked and clothed child are almost identical, which is due to the similar tones of the child's complexion and his clothing. In the last version, the child's dress presents diverse colorimetric values than the first two, as expected also simply by looking at the painting.

## 5. Some final considerations and conclusions

The results of this research demonstrate that although the differences in colour in the four different versions of the same scene could be perceived by naked eye, the spectrophotometric colour measurements provided clear and objective information about the early palette Picasso used in introducing the emotional effects into the analysed paintings. Hence, the colorimetric values obtained from reflectance spectra of relevant areas contribute to the understanding of the evolution in the tones and hues Picasso employed to enhance the dramatic impact of the scene represented in the four paintings. From a psychological and artistic viewpoint, the natural scale of the characters in the final version of "Science and Charity" conveys a sense of veracity and transmits stronger emotional charge. However, it is through the evolution of

the chromatic elaboration that Picasso truly managed to accentuate the drama. For instance, the interplay between the clear and sombre architecture and the areas that remain in shade highlight the dramatic nature of the scene in which also the healthy characters are contrasted with the sick woman. Every small detail and larger organisation of the elements, for example the doctor's prominent presence in front of the patient's emaciated face, contribute to the pathos and imminent fate. The pallor of the patient is accentuated plastically through the comparison with the white of the sheet but also by the skilful choice of pigments. Although the artist tended to use lead whites (both pure and in the mixtures), here he decided to add zinc white to accentuate the sickness, now evident in the woman's mortuary complexion. These two different white pigments were identified by means of FORS and HSI techniques (Bacci et al. 2007).

The healthy-looking child, on the other hand, offers a positive view of the continuation of life. In one of the first versions his vulnerability is emphasised through his nakedness and the direction of his arms, as he reaches towards the sickly mother, but in the subsequent versions the drama has decreased: in the sketch MPB 110214 he is clothed, and in the final painting he not only wears a nice dress but also gathers his arms, thus remaining connected to the scene under the protection of the nun.

Throughout the painting process, the doctor is depicted as a figure of dignity; he wears a sober black frock coat that forms a contrast to the shining white collar and sleeves. In this way, Picasso had completely transformed the initial intention of presenting a certain luminosity by placing the characters in a chiaroscuro framework that accentuates the drama of the event.

This big canvas painting is remarkable in many ways; first of all, it was executed by a 15-year old artist during the formative years of his brilliant career. Moreover, although some elements in the scene do not exactly correspond to reality (i.e. the technically well-executed cornucopia decorating the wall, which is a discordant element), the greatness of the artist's achievement comes across through the painting's pictorial quality and the powerful message it conveys to its observers.

## 6. Conflict of interest declaration

The authors state that no actual or potential conflicts of interest exist including financial, personal or other relationships with other people or organizations within three years of beginning the submitted work that could inappropriately influence, or be perceived to influence, their work.

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## References

- Gage J. (2006) 'Colour in art', Thames & Hudson, London.
- Fuster-Lopez L., Jiménez R., Aguado E., Andersen C. K., Izzo F. C., Murray A., Picollo M., Valcarcel J., Vicente A., Vila A. (2018) 'Con permiso de Picasso. Aproximación a los mecanismos de degradación en pintura moderna', *Actas de la 19ª Jornada de Conservación de Arte Contemporáneo Museo Reina Sofía, Madrid, 2018*. In press.
- Buswell G. T. (1935) 'How People Look at Pictures: A Study of the Psychology of Perception in Art', The University of Chicago Press, Chicago.
- Arnheim R. (1974) 'Art and visual perception', University of California Press, Berkeley and Los Angeles.
- Gombrich E. H. (1968) 'Art and illusion: A study in the psychology of pictorial representation', Phaidon, London.
- Gage J. (1999) 'Color and meaning: Art, science, and symbolism', University of California Press, Berkeley and Los Angeles.
- Borren F. (2016) 'Color psychology and color therapy; a factual study of the influence of color on human life', Pickle Partners Publishing.
- Parraman C. (Ed.) (2010) 'Colour Coded', Society of Dyers and Colourists, Bradford (UK).
- Striova J., Ruberto C., Barucci M., Blažek J., Kunzelman D., Dal Fovo A., Pampaloni E., Fontana R. (2018) 'Spectral Imaging and Archival Data in Analysing Madonna of the Rabbit Paintings by Manet and Titian', *Angew. Chem. Int. Ed.*, 57, pp. 7408-7412.
- Dooley K. A., Conover D. M., Deming Glinzman L., Delaney J. K. (2014) 'Complementary Standoff Chemical Imaging to Map and Identify Artist Materials in an Early Italian Renaissance Panel Painting', *Angew. Chem. Int. Ed.*, 53, pp. 13775–13779.
- Gual M., Jiménez R. (2010) 'Ciencia y Caridad al descubierto', *Colección Focus 1*, Ed. Museu Picasso, Barcelona.
- Jiménez R. (2018) 'Science et charité: restauration, étude, technique et recherches', in Bouvard, Émilie, Coline Zellal (eds), *Picasso. Chef-d'oeuvres!* Paris, Gallimard / Musée national Picasso-Paris, pp. 44-49.
- [https://www.konicaminolta.com/instruments/download/instruction\\_manual/color/pdf/cm-700d\\_instruction\\_eng.pdf](https://www.konicaminolta.com/instruments/download/instruction_manual/color/pdf/cm-700d_instruction_eng.pdf)
- Zervos C. (2013) 'Pablo Picasso - Catalogue of works, 1895–1972', new revised edition, Ed. Cahiers d'Art, Paris.

Wyszecki G., Stiles W. S. (1982) 'Color Science: concepts and methods, quantitative data and formulae', Wiley and Sons, New York.

CIE Publication No 15.2 (1986) 'Colorimetry' (2nd edition), Bureau Central de la Commission Internationale de l'Éclairage, Vienna.

ISO/CIE 10526 (1991) 'CIE standard colorimetric illuminants', International Organization for Standardization, Geneva (CH).

ISO/CIE 10527 (1991) 'CIE standard colorimetric observers', International Organization for Standardization, Geneva (CH).

Bacci M., Picollo M., Trumpy G., Tsukada M., Kunzelman D. (2007) 'Non-invasive identification of white pigments on 20th century oil paintings by using fiber optic reflectance spectroscopy', *Journal of the American Institute for Conservation*, 46, pp. 27-37.

# Education about colour: a look at some authors from the 19th and 20th centuries in Italy: Corrado Ricci, Maria Montessori and Giuseppina Pizzigoni

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## ABSTRACT

In this contribution, the aim is to juxtapose three figures who, in spite of their very different skills, were interested in the element of colour. The first is Corrado Ricci, an illustrious art critic and historian, who started to study children's drawings at the end of the 1800s, making him one of the first in Italy to do so. In 1877, he published a small pamphlet called *L'arte dei bambini (The art of children)*, which included a special reflection about the theme of colour. Conversely, the other two authors are pedagogists: Maria Montessori (1870–1952), an internationally renowned figure who also dealt with the theme of colour through her method, equipment and tools, and Giuseppina Pizzigoni (1870–1947), a pedagogist who dedicated positivist attention to the theme of colour, which she linked to natural aspects and a connection to the vegetable garden, a cornerstone of her method. At the end of this historical overview, a survey that was conducted by the Istituto Comprensivo Rinnovata Pizzigoni is presented, in an attempt to observe the colour-related proposals that have been made.

**KEYWORDS:** Colour, education, children, school, pedagogy, Montessori, Pizzigoni

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## 1. Introduction

Interest in children's drawing and their use of colour is a research theme that has been observed in a systematic manner since the early 20th century. Re-examining how certain Italian authors have tackled this theme, as pioneers, is a significant concept, because it allows us to examine the idea of a child beyond the cultural context, as well as their potential. It is from this that the educational proposals formed are directly derived. The choice of authors, who certainly belong to a much wider overview, stemmed from a careful research for those who had mentioned the theme of colour in their writings. Without doubt, the first was Corrado Ricci (1858–1934), who established himself as the pioneer in the study of children's drawings and helped to separate these from the idea of incompetent attempts. On the other hand, the other two figures – Maria Montessori (1870–1953) and Giuseppina Pizzigoni (1870–1947) – allow us to see how pedagogical declination supports the proposed actions, moving them towards different paradigms that are always linked to the theme of colour.

## 2. Corrado Ricci and his interest in children's drawings

Corrado Ricci's focus on children's drawings and the use of colour is an important action, one that is revolutionary compared to many scholars from that period. Firstly, we must outline his background. Ricci was a writer, an art historian, a general director of fine arts and antiquities and a scholar of S. Luca. It was an accident that led him to study children's drawings, even if his eyes were certainly trained and attentive towards the various forms of artistic expression. In his book *L'arte dei bambini*, he recounts the episode that gave rise to his new-found interest. This is what he tells us: "One day in the winter of 1882–83, as I was returning from the Certosa di Bologna, I was caught in the rain and forced to shelter under the portico [...]. I did not know that there was a permanent literary and artistic exhibition beneath these arches, which was of little aesthetic value [...]. The sadness of that day [...] reconciled me with the clever art of children and gave me the idea for this study." (Ricci 2007). This new focus pushed Ricci to observe the works of children: to collect them, catalogue them and study them. The assistance provided by Raffaele Belluzzi, multiple masters and Adolfo Venturi, an art historian, was fundamental, however, in achieving this goal. It was the latter who collected 250 children's drawings or had them collected. This small pamphlet was the result of these careful studies of children's works, which experienced growing success, as well as quick and constant dissemination over time, even

crossing beyond Italy's borders. Ricci underlines the push of children towards creating drawings. These are experienced as creative projects, even if they are imperfect and have specific characteristics, which manage to overcome mere imitation and reveal the presence of stadial steps. The key words highlighted by Ricci as specific features that appear in many of the children's works studied are: transparency, integrity, integral version. These are seen as direct evidence of a growth process that proceeds on a trial-and-error basis, by trying to overcome the many problems that are inevitably caused by representing some on a two-dimensional surface, combined with an inevitable lack of graphic experience and a strange outlook on the world.

Ricci's work also received a lot of recognition from overseas. What is still striking to this day is the decision to dedicate attention towards children's drawings, which many scholars at the time considered to be an imprecise and imperfect product that did not warrant being studied.

Within Ricci's writing, there is a paragraph called *Il bimbo e il colore (The child and colour)*. The author highlights that previous scholars, such as Hugo Magnus and Gladstone, who based their works on readings of Homer or hypothetical scientific experiments, stated that people in the past saw only a few colours. This idea, however, was not limited to people in antiquity: "It is helpful to note, however, that this colour blindness was attributed to populations in antiquity, savages and children." (Ricci, 2007) By looking into the various hypotheses, Ricci comes to state that: "In terms of savages, repeated and scrupulous experiences have demonstrated that their sense of colour was in no way defective. All that is left for me to discuss is children." (ibid.) He quotes Preyer, who stated that children first saw yellow and red and, only later, green and blue, which was otherwise confused with grey. For Ricci, it was easy to dismantle this hypothesis, by highlighting the reason for this lack of ability to distinguish as being not a visual difficulty or limitation, but rather a circumscribed development of the appropriate language. "Their pictorial lexicon is very limited, and, in terms of art, they mostly do not use the various derivations for the term "painter" as someone who paints; the act of drawing and colouring, to them, is referred to as "painting". [...] Imagine, then, if one could acquire the phraseology of the chromatic scale! In fact, after performing experiments with 306 children, Bono concluded by saying that the illusion of colour blindness in children – just like in savages and people in antiquarian times – stemmed from the lack of language and is a false comparison." (Ricci 2007)

However, this statement was not intended to say that children should be left alone on their journey to explore and discover: "There is certainly a need to educate



children's sense of colour, as they educate their own drawing skills. This is not because it is accurate that they do not see colours, but because they discover a reasonably harmonious response to what is. This is because, in the same way that they see things well but do not know how to depict them with signs, they see colours well and do not know, or care, about finding them in their palette. The various gradations and the semi-tones of the shades reach the retinas of their eyes, but not their artistic intelligence, and are generally satisfied with bright colours that are close to what is true." (Ricci 2007) The advice given to teachers and parents is to encourage the children's attention to what they naturally observe, thus strengthening their accuracy in reproducing it and, in particular, identify the various tones in the shades. In concluding his text, Ricci states that the child reproduces the object by following what their memory suggests, later passing to a more exact observation, due to the expansion of their knowledge and skills that is stimulated by education.

### **3. Maria Montessori and colour**

By passing from an author like Corrado Ricci, an art historian, to a profoundly different figure like Maria Montessori, we can discover a different relationship with the theme of colour. A doctor and pedagogist, she was extremely passionate about the life of children – in particular, disadvantaged children – and also interested in children's relationship with colour. It must be immediately stated that Montessori, when designing specific didactics for her method, and dealing with this theme, did not only study the childhood use of colour in graphic depictions, but considered a global approach that involved the physical, emotional and cognitive aspects of the child. For the sake of simplicity in this argument, we can argue that her attention focused on different perspectives; for this brief analysis, at least four can be highlighted:

- 1 – the creation of educational-scholastic environments;
- 2 – the design and identification of scholastic/developmental materials;
- 3 – artistic education;
- 4 – physical-health checks and sensory education, from the perspective of visual distinctions.

In order to confront these points, we will use phrases written by the author herself, as we have done for the previous author. In this case, these are taken from a variety of texts, in an attempt to create an overview, the focus of which will always remain colour.

For the first and second point, one recalls that the environment and materials are fundamental elements in the Montessori method. In fact, they guide the child, promoting independence facilitating constant control over the error, without the need for the teacher's presence to be pervasive. "It is not only objects for sensory education and culture, but the entire environment that is prepared to make error control easy. The objects, from the furniture to the individual development materials, act as denouncers, whose calming voices cannot be escaped. The bright colours and shimmer denounce the stains [...] and each child hears the guidance as if they were alone with the inanimate teacher" (Montessori 2013).

Specifically, the objects must be designed with specific characteristics, with the idea of their learning objective not confusing too many qualities. The words of Montessori point to this specific idea: "The isolation of a unique quality in the material. Any object that we want to use for sensory education will present, by necessity, many different qualities, such as weight, texture, colour, shape, dimension, etc. It is necessary to isolate a single quality of the object from among the many. [...] If one wishes to prepare objects that serve, for example, to distinguish between colours, it is necessary to build them with the same substance, form and dimension and differentiate them only by colour" (Montessori 2013).

Another fundamental aspect for the proposed objects – though not only these – is linked to aesthetics. "Aesthetics – another characteristic of objects is to be attractive. The colour, shimmer and harmony of the shapes are things that are considered in everything a child is surrounded with" (Montessori 2013). The objects, which are designed according to the characteristics outlined above, have a voice that is so intriguing that it attracts children: "The voice of things. It is true that the teacher supervises, but various kinds of things "call" to children of various ages. The shimmer, colours and beauty of beautiful, adorned items are the "voices" that capture children's attention and stimulate them into action" (Montessori 2013). This shows us how the presence of the colour element, when it is suitably considered and included, can act as an incentive to facilitate children's work. When comparing environments and architecture, it is useful to remember the first experience of the "Casa dei Bambini" on via dei Marsi, 58, in the San Lorenzo neighbourhood of Rome; this was inaugurated on 6 January 1907. "Talamo's wonderful idea was to gather young children who lived in the house, aged between 3 and 7 years old, and to bring them together in a room under the direction of a teacher, who also lived in that home" (Montessori 1909). Education was visually manifested in the care provided for the furnishings, the size of the child, the layout of the environment, for which

the same young people became the first caretakers. Here, the choice of colours became a characterising element.

In terms of the third point, which relates to artistic education, the pedagogist moves away from the proposal of free drawing, which had become popular in those years. "So-called free drawing does not come into my method: I avoid the immature, unnecessarily exhausting tests and scary drawings that are in vogue in modern schools with advanced ideas" (Montessori 2013). A few pages later, she notes: "In conclusion, the best way to influence drawing is not to let it be free, but to prepare natural ways to produce it, that is, to train the hand" (Montessori 2013).

In her observation about drawing, her attention is instead focused on two fundamental elements that she has identified, for which she proposes a series of exercises that aim to train the hand and the eye. "There are various elements in drawing, such as outlines and colours. For these two elements, we can now trace the outlines of the joints and fill in the drawings with lines; this prepares the hand for a secure muscular exercise. For colours, we provide brushes and watercolours, with which one can create drawings, even when the outlines have not been prepared. We also provide pastels and demonstrate how they can be used. Finally, it is possible to create artistic representations by cutting out coloured pieces of paper, such as those which Oswald, the famous Vienna-born physicist, prepared for artistic purposes. These pieces of paper, which are finely gradated in terms of colour and scientifically prepared, lend themselves to the appreciation of the harmony of colour combinations. These two separate elements – lines and colours – are determined and perfected independently of each other. These are acquired by the individual, who becomes capable of expressing themselves artistically using the two elements together" (Montessori 2013).

Specifically for the fourth point of this discussion, which deals with visual and auditory distinctions, Montessori provides a specific material for colours, which she calls Colour materials: "The material that leads to colour recognition (education of the chromatic sense) is as follows, which I have established after a long series of trials on regular children. [...] The definitive material consists of tablets that have brightly coloured silk threads around them [...]. I chose nine shades, with each corresponding to seven gradations of differing intensities: therefore, there are 63 colour tablets. The shades are: grey (from black to white); red; orange; yellow; green; turquoise; purple; brown; pink" (Montessori 2013). In another text, *Il segreto dell'infanzia (The secret of childhood)*, she recounts a small episode, which begins a reflection on children's skills regarding colours. A teacher, who was experimenting, with much difficulty, with the

method, was unsuccessful in delegating control of the materials to the children, as predicted. The culmination involved the coloured tablets: "One day, though, the box, which contained almost 80 tablets with different gradated colours, fell from the teacher's hands. I remember her embarrassment, because it was difficult to recognise so many colour gradations. The children, however, ran over and, much to our surprise, quickly put all the gradations back into place, showing that they have a wonderful sensitivity to colours, even greater than our own" (Montessori 2017). This subtle ability to distinguish, which is found in children, completely changes the idea of inability that, only a few decades before, in the age of Corrado Ricci, had been hypothesised. It recognises that children have an excellent level of focus, understanding and interpretation in terms of colour. Some exercises were also planned within the field of physical and health checks, taking into account the correct growth of the child. "We must begin the process with very few contrasting stimuli, and then establish a number of similar objects that have an increasingly fine and imperceptible level of gradation. [...] for the colours, one will choose the most bright and contrasting shades, such as red and yellow [...]. The final exercise, that of gradation, consists of putting similar but confusedly mixed objects in order of their gradation [...] The presentation of a series of yellow objects will be analogous, but the shade will gradate more clearly, from dark to bright. [...] Said objects must be arranged beside each other, according to the place that their quality establishes in the gradation" (Montessori 2013).

In conclusion to what has just been outlined, we can state that Montessori was one of the first scholars to dedicate in-depth attention to the relationship between children and colours, its potential to act as content to be proposed and as a possible factor to positively influence learning skills, by using it as both a didactic tool and in scholastic environments and as a subject in various disciplinary fields.

#### **4. Giuseppina Pizzigoni and colour**

Giuseppina Pizzigoni, a Milanese pedagogist, had a different outlook. She created a method based on science, direct and personal experience and the didactic use of the vegetable garden as a focal point for all educational activities. For her, examining the theme of colour occurs through a scientific outlook. In terms of life drawings to be taken from the outdoor world, the observation of trees in spacious courtyards and the various types and shades, these become living material that can also be reflected on in terms of colour. "I always begin teaching drawing from life drawing, not from a drawing that has already been

traced on the board or presented in models. From the very first class, I place the children in front of a bare tree and, after encouraging them to observe it, tell them to draw it. Another time, I ask them to consider an evergreen plant, for example, a pine tree [...]” (Pizzigoni 1971).

This close observation is not limited only to drawing, but also covers many other disciplines, including Italian. For example, here are some pages taken from a fifth-class diary, a tool for collective writing, which focuses on the specific offerings of nature: “7 October. How the plot from last year has been infested! Some wheatgrass and gallant soldier are suffocating the strawberries and black nightshade and amaranth; it hides the salad and the beautiful green tufts of the sugar beets. We have observed that the flowers and the leaves from the black nightshade resemble the leaves and flowers of the tomatoes and the potatoes; in fact, all three belong to the Solanaceae family” (Pizzigoni 1971).

This attention, which is accurate both scientifically and, at the same time, aesthetically, was also the base for the creation of said garden, which provided a series of colours, flowers and constantly different views, and allows children to constantly train their gaze on a panorama with natural colours that are in a constant state of renewal. The same interest that was shown for external spaces was also found in interiors. For these, she had designed a refined décor, tackling the criticism of those who believed this was without merit: “For this reason, the Scuola Rinnovata took care to prepare an artistic environment and the decorate the halls and corridors, the gym and the refectory with selected paintings that had a certain degree of gradation in terms of their relationship with the students’ powers of artistic comprehension” (Pizzigoni 1956). The environment, observations and concrete actions of the children, then, are fundamental elements in training and informing children’s gaze and creative abilities, taking colour into consideration as a fundamental element. Turning back to colour, a point in the chapter dedicated to drawing includes a small paragraph called “Colouring”. Here is what is written: “The use of colour plays a large role in drawing lessons; from primary school to the final class, colour has a role to play, even though it is achieved in various ways. This ranges from knowledge of the basic shades to the creation of shades and their gradation. This can be obtained with coloured pencils, pastels, watercolours and oil paints and special varnishes, the latter of which are effective for colouring toys. The colour is used to highlight the design of geometric figures and still-life drawings; furthermore, it brings animation to spontaneous design” (Pizzigoni 1971). As we have been able to see with this pedagogist, colour is never an isolated proposal, but it is strongly implicated in the practice of investigating and discovery, pushing the conceptualisation process to a later step. It is a scientific, experimental colour and a necessary piece of data to carefully discover and explore nature and the world.

#### **4.1. A look at the current situation**

Staying within the framework of Pizzigoni’s method, within the development course needed to become a teacher, which was organised in collaboration with the Università di Milano-Bicocca and the Istituto Comprensivo Rinnovata in 2018, a point that was dealt with in this process was linked to perception and the practice relating to colour within this school. After a continuous period of in-class training, the majority of people following the course noted the presence of many educational actions that involved colour, with a prevalence towards the use of colour pigment. Their hypotheses for future activities, however, have been directed towards a rich and innovative range of possibilities, which are not limited to the specific field of image education, but are aimed at the relationships between colours and music, colours and science, colours and language.

## **5. Conclusions**

This brief discussion – with its historic element – aimed to show how colour has also been a significant player in education programmes in the past. Very different figures have studied it and proposed varied experiments and different uses. Reading the texts of these relevant authors also suggests that colour is a field with thousands of possibilities, one that is interesting for teachers and educators today. A suggestion for young teachers is to re-read some of these tests and launch small experiments based on recognised and codified activities; from that base, one can discover new processes with more innovative and interdisciplinary paths.

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## **8. Short biography of the author**

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years, she has collaborated with many museums and cultural heritage institutions, on educational and didactic projects. The theme of colour is one of the topics that she deals with in her research.

## **References**

Montessori, M. (2013) 'La scoperta del bambino', Garzanti, Milano.

Montessori, M. (2017) 'Il segreto dell'infanzia', Garzanti, Milano.

Pizzigoni, G. (1971) 'Le mie lezioni ai Maestri d'Italia', Editrice La Scuola, Brescia.

Pizzigoni, G. (1956), 'Linee fondamentali e programmi e altri scritti', Editrice La Scuola, Brescia.

Ricci, C. (2007) 'L'arte dei bambini', Armando, Roma.

# From *Dots* to *Atoms*: “Light and Color” Techniques in Fifteenth and Sixteenth Centuries’ Painting

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## ABSTRACT

The present contribution discusses the latest outcomes of a research in the history and in the criticism of Early Modern Art, with a focus on the development of colored ‘dotted’ patterns. Given that the so-called ‘Primitives’ Tuscan Masters, such as Alesso Baldovinetti and Giovanni di Paolo, were particularly skilled in the use of this peculiar technique, which is found especially embodied in tempera works produced in the course of the fifteenth Century, this research line can be also extended to artistic practices operated in the subsequent Century. In fact, it is possible to establish a ‘European paradigm’ in this regard, and to track the development of dotted techniques also in *Cinquecento* illumination, whence the presence of such details becomes also a subject in the artistic literature. Artists who have had a central role in the export, and in the development of this ‘style’ (Baldovinetti, Giovanni di Paolo, Attavante, Antonio de Hollanda) will be presented and addressed throughout the present study. Notes and historical fragments will be here discussed for the reading and the analysis of ‘punctuation’ manners, and for a future historical turn in the understanding, and the knowledge of those “raffinate technologies” used for coloring purposes.

**KEYWORDS** Dots, Illumination, Baldovinetti, Highlights, Attavante, Choir Books, Authorship

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## 1. Introduction

The custom of 'painting with dots', so the actual presence of 'dottily' techniques and patterns in the art of Early Renaissance Masters is analysed in the present contribution. The focus is placed on the possible connections, in light of this, between artists active in the execution of easel and mural painting works, and those active in miniature art works over the period and up to the first decades of the sixteenth Century. The present study invites scholars in art history with an interest into the 'science of color' to reconsider, as a consequence of the emergence of such visual elements, the tribute of authorship related to the artists and their works of art, as well as their influence and place of relief in the history of the circulation of visual models among European Countries, and trading routes.

By showing and tracking the developments of 'dotted' techniques in the fifteenth and sixteenth Centuries, this study aims to highlight the process in its own historical period of formation. The aim is that to recover, precisely, the degree of uniqueness with regard to the use of dots in *Quattrocento*, and up to *Cinquecento* art, with supporting material evidences. In *Quattrocento* painting, as this study wishes to demonstrate, the dots appear as being especially adopted to represent flickering highlights over the edges of laminate surfaces, and over fabrics and precious details covering bodies, or to give a rhythmic, 'textile-like' design to rocky landscapes.

### 2.1 Art Criticism, 'Pointillisme', and Early Modern Art

In order to provide a context of reference in the criticism and in the theory of art for such a captivating, yet very complex subject matter as it is the description of light and the decorative details made with pure 'stippled' color notes, it is essential to start with an article published by Roger E. Fry in 1911. His case exemplifies clearly how art historians have dealt at first with the interpretation of the use of 'dots' in earlier art. In Fry's words, the coloring technique visible in a *Profile female Portrait* made by the Tuscan Master Alesso (Alessio) Baldovinetti – further analysed in the present study – resounds as an early form of *pointillisme*, as follows: "Here the whole of the modelling of the high lights upon the flesh is effected by the use of innumerable small dots of light [...] and, so far as I am aware, neither Paolo Uccello nor Piero della Francesca ever used Baldovinetti's *pointilliste* method" (Fry 1911, Fig. 1).

Fry confirmed the *Portrait's* authorship on the basis of his own observation of a "constellation of minute dots of light [and] colour", smoothly applied on the painted surface, allegedly, likewise as in a Seurat's large Neo-impressionist

canvas, as something never seen before, nor characterizing the works made by other leading artists active alongside Baldovinetti.

Thus, at the very beginning of the twentieth Century and henceforth, the use of 'dots' in fifteenth Century painting has been interpreted as a visual device for the expression of plastic values comparable in technique to the color handling showed by Modernist Masters, and especially by the Neo-Impressionists. With regard to the legitimacy and substantiality of such a comparison, it is worthy to refer to the comments made afterwards by Ruth W. Kennedy in her monograph on Baldovinetti, where a fundamental distinction is drawn between the modernistic, and the fifteenth and sixteenth Centuries' meticulous applications of dots on the material supports: "Signac and Seurat have familiarized modern eyes with this convention of representing by dots or "points" the effect of the rays of light falling on a reflective surface, but in the Quattrocento it was unique. However representational the device was in principle, Baldovinetti, as always, handled it in a decorative way, so that the constellations of dots became patterns in themselves. The separate identity of each dot is maintained by its very distinctness and solidity of form, thus tending to prevent the fusion of images demanded by exact Pointilliste theory" (Kennedy 1938).

A great display of inventiveness and intuition had then characterized the reams of ink written by the critics in the twentieth Century to outline the fundamental connections noticed between Early 'Primitives' painters, and the modernistic ones. Though those valuable efforts have been crucial in revealing the artistry and the seriousness of contemporary Masters, this has nonetheless fostered the making of audacious associations that nowadays would need to be revised. In this literary context, also Fry's views would need to be seen and placed in their own historical background, as being part of a broader series of parallels grown-up within the academic literature, as well as within the current press, in the wake of the fortunate associations made among artists particularly in vogue [1]. It is not the main scope of this contribution to reconstruct again the events connected, for instance, to Bernard Berenson and Roberto Longhi's respective historiographical rediscoveries and readings of Piero della Francesca's feeling for nature, in line with Paul Cézanne's; in this light, it is enough to recall here that Longhi did not forget to make his references to "Seurat's dusty weighing" ("pesatura pulviscolare del Seurat") in his interpretation of the *Dream of Constantine* in Arezzo, or to celebrate the conjunction "via the atmospheric motes" of the rays of light projected onto the wall in the background with the luminous source visible in the *Senigallia Madonna* (Longhi 1927).

In twentieth Century criticism, the re-evaluation of these 'Primitives' Masters is done also on the background of the observations made about their sensibility for nature and landscape in a realistic mode, and therefore on the basis of their involvement in the development of a genre acquiring more autonomy and space, following models already established in Northern European art. Without steering off course from the subject of the present study, it might be useful to recall, for instance, that the term "*macchiaiolo*" was occasionally used to define other cases of 'dotted' luminous colorism visible in Early Master's art (Brieger et al. 1969).

## 2.2 Giovanni di Paolo and Alesso Baldovinetti: sources for a history of the 'dotted' handling of color in *Quattrocento* Art

The Sienese Master Giovanni di Paolo, in a way intriguingly similar to that showed by Baldovinetti, is found by Cesare Brandi displaying a very original treatment in his landscape details, defined in 1941 as a "*punteggiatura*" (punctuation, dotting), "a trace of big flour-like grains." (Brandi 1941b). In a study written by Maria Luisa Gengaro (1932), with whom Brandi ideally establishes a dialogue, the author interprets Giovanni di Paolo's art as being partly derived from Lorenzetti's art, and partly from the miniature works displayed in Franco-flemish *Books of Hours*: "[...] on a stylistic basis, it is possible to say that in Giovanni di Paolo it is manifested a principle of that tendency towards the deformation through means of light that will become the basis to any creation in modern art" (Gengaro 1932). The same is also noticed by Cesare Brandi, who writes that, inspired by the knowledge of illumination technique, Giovanni di Paolo translated in vernacular Tuscan painterly language the descriptive attitude of those pastoral tales usually flourishing in '*très riches heures*' Books (Brandi 1941a).

The characteristic white pebbles visible in Giovanni di Paolo's tempera panel scenes are also present in the *Entering of St. John the Baptist into the Wilderness* (1454, London National Gallery, Fig. 2), as well as in the *Baptism of Christ* (1454), a work of art that, in his composition, reminds of the same subject represented by Alesso Baldovinetti in one of the three panel depicted by him as a pupil to Fra Angelico, for the completion of Piero de' Medici's *Silver Chest* (1448-1452). The analogies discernible between the two Tuscan Masters do not simply belong to the general configuration of these small boards, but comparisons can be also made looking at their color handling of small figurative details: it is, in fact, possible to notice that the two have made use alike of 'small spots of paint', namely minute and bright touches of pure color in order to give the relief, and to suggest the roundness of specific objects. Baldovinetti's *Baptism*, apart from the

filigree of white dots decorating the borders of Christ's garments, shows again the bright spotted technique in the reflections of the highlights upon the stones and in the water (Fig. 3). This peculiar plastic conception, and treatment of color distributed as to suggest an effect of 'punctuation', also similarly comes up in the *Portrait* made by Baldovinetti (1465), and attributed to him by Roger Fry (1911). According to the British author, having initially made use of dots to achieve tone gradation, Baldovinetti would later develop a real obsession for the use of this color technique (Fig. 4). Besides miniature painting, a possible source of inspiration for this innovative use of painting with dots can be either found in the Primitives' knowledge of mosaic art [2] (Vasari 1958; Chastel 1954/55), and of powdered gold technique. With regard to the latter, 'shell' gold has marked a first step in the transition from lamina to pure color, and towards the use of gold "like any other colour" (Ames-Lewis 1984), for the advantages provided in terms of optical and tactile values' suggestions by the thin shape given to the raw material. In view of this discourse, Baldovinetti's London *Portrait*, while presenting gold leaf applied with an orange-colored mordant in the larger dots impressed on the dress, also shows a definitive innovation in the bright jewels depicted with pure stippled color notes [3], by means of which the artist obtained effects normally achieved by others with powdered gold, as it is visible, for instance, in Gentile da Fabriano's midwife robe in the *Adoration of the Magi*, or in Domenico Veneziano's *Madonna Berenson*, and in Jacopo Bellini *Madonna of Humility*'s mantle. With regard to the use of powdered gold technique, it is documented (Kennedy 1938) that Alesso Baldovinetti and Luca della Robbia – often working side by side in the same Florentine sites like Santa Trinita, and especially in San Miniato – made use of it in the golden backgrounds of the ovals, and in the interstices between the flower bouquets designed for the sepulcher of the Bishop Benozzo Federighi in Santa Trinita, Florence (about 1454). In modern criticism (Bartalini 1990), Alessio Baldovinetti is praised for his mastery of the "science of color", a feature that – as already noticed by Roger Fry (1911) – is traced back to his apprenticeship with Domenico Veneziano, and to his young panel scenes for Fra Angelico's *Armadio degli Argenti*: "In the Wedding at Cana (Fig. 5), he was seeking for intense effects of twinkling, and of luminous refraction in the metallic shine of the jugs, such as in the glass of the small windows; but not at all different, yet totally oriented towards the examples of the Veneziano, resulted the chromatic texture: made of large divisions of thick layers of colors, precious and varied, "raised" by white highlights and unified in a diffused light." In this critical context, the artist also emerges for his ability to capture within his paintings some of the optical values belonging to the art of Flemish Masters: "The dialogue that he had taken most

into consideration was that with the Flemish artists; and the perspicuousness, the painting all made of penumbra and optical "values" in the Annunciation [...] had now followed that direction." (Bartalini 1990). In addition to this, it has to be recorded that Baldovinetti worked for influential international patrons in the Chapel of the Cardinal of Portugal (Florence, San Miniato al Monte) in the years 1466-1468 (Poggi 1909), an extraordinary sepulcher-Chapel to which all the leading Masters available in Florence in 1459 (year of the death of Cardinal Jaime of Lusitania) were called to contribute. In the person of the Bishop of Algarve Alvaro Alfonso, the members of the Aviz Portuguese dynasty hired Alesso Baldovinetti in 1465 for the decoration of "tutti e vani della chappella" (Hart et al. 1964). Many studies confirm that the artists employed in the *impresa* were asked by their clients to work 'alla fiamminga', that is in the 'Flemish manner' [4], according to the artistic tastes of the patrons. (Apfeltadt 2000). In the critical evaluation of the optical values performed by Baldovinetti's mural paintings in the 'Portuguese' Chapel, many analogies have been found with the art of illumination "[...] you never see broad, confident brushstrokes, a large mass of chiaroscuro, because every aspect of light and color is achieved by minute strokes, gentle dabs of the brush, as though there were nothing but miniatures everywhere." (Londi 1907).

### 2.3 From Alesso Baldovinetti to Attavante degli Attavanti: sources for the 'miniaturized' style in Cinquecento European Illumination

In this respect, and with regard to the influences exercised by illumination practices in the development of "dotted" details in the years here considered, it is useful to record that especially in Florence and Siena a strong tradition in miniature art had flourished among easel painters from the fourteenth Century, with Lorenzo Monaco, Pacino di Buonaguida, Fra Angelico, and other Masters especially active within the Camaldolese Monastery of Santa Maria degli Angeli based in Florence. At the time, the Florentine miniature style was much influenced by the novelties of the International Gothic, divulged in Florence by Gherardo Starnina who had returned from his Spanish sojourn in 1403 (Kanter 1994). Among the series of eighteen *Antiphonaries* (Florence, Biblioteca Medicea Laurenziana, Choir Books 1-19) produced and illuminated within the same Florentine Monastery since the late fourteenth Century (about 1368) [5], worthy of reconsideration are the possible inspirational motives for the decorations made in the Choir Book Ms. *Cor. Laur. 4*. This is the ultimate finished piece of the whole series, started in 1410 but only completed by the illustrious Florentine miniaturist Attavante degli Attavanti in 1505-06; the precious and beautiful scenes illuminated by Attavante have been

generally interpreted so far only as derivations from the manner of Ghirlandaio (Levi d'Ancona 1995), who had realized the miniature in *f. 16r*, ms. Ross.1192, Vatican Apostolic Library. However, in the general scheme of the compositions, and in the details of the decorations a filiation from Alesso Baldovinetti's art of painting can be guessed and so it is here proposed; such a plausible connection has never been mentioned, nor guessed, in the major studies about the *Choir Books*. If a comparison is made, in fact, between several folios from the Ms. Choir Book 4 and Baldovinetti's larger works, these assumptions appear as to be clearly consistent, as follows: a) a first case in this regard is found in the opening full-page miniature of the folio 1v (Fig. 6), closely resembling the general composition of Baldovinetti's *Holy Trinity* (Fig. 7), especially in the design of the almond-shaped putti surrounding the Holy Trinity (Fig. 8); b) in the folios 18v (*Christ among The Apostles*), 33v (*The Call of Peter*, Fig. 9), and 43v (*The Feeding of the Multitude*, Fig. 10), a general orchestration for the depicted soils can be observed, together with the characteristic dotted pebbles, similar to that already found in the small panels made by Baldovinetti, and Giovanni di Paolo (Fig. 11); c) in the folios 7v (*The Procession*, Fig. 12), and 56v (*The Cleansing of the Temple*, Figs. 14, 16), the coloring and the treatment of the columns, and of the floor follow Baldovinetti's very personal imitation of granite and marble-like surfaces, as visible in both his *Annunciations* (Portuguese Chapel, Fig. 13; Uffizi Gallery, Fig. 15;), and in the surviving mural fragments from the decorative frescoes of the Church of St. Egidio; d) finally, the striking threadlike calligraphies of the beards in the two artists can be reasonably associated (*f. 1v. oculi with Prophets*, Fig. 17). A very captivating one, is the account of Attavante's artistic personality offered by Paolo D'Ancona, in his study of a humanistic manuscript kept at the Biblioteca Corsiniana in Rome (1910). The profile of Attavante is given relying in particular on his calligraphy, and on his personal approach and carefulness in the execution of minute details such as hair and beards. In this study, Attavante is celebrated as "the one who has made the very noble art of the miniature express its last and most ornamented word" (D'Ancona 1910). The derivation of Attavante's decorations from Ghirlandaio is maintained by Mirella Levi d'Ancona (1993-94), who describes Attavante's executions of details as a clumsy manner, in opposition to Ghirlandaio's perfection: "Attavante depicts figures that fall, deprived of any gravity and anatomy; on the contrary, Ghirlandaio's figures are solidly attached to the ground, and anatomically correct." (Levi d'Ancona 1993-94). A different source of inspiration for these miniatures, as it is supposed here, can be the reason behind the differences noted between Ghirlandaio and Attavante. In this respect, the artistic personality of

Attavante results aligned with that tradition of experimental artists taking licenses and distance from absolute perfection, more imaginative also in the conception of anatomical structure; the same is told of Paolo Uccello, for instance, by Lionello Venturi in 1930 [6]; similarly, in fact, Levi d'Ancona writes that the hands made by Attavante show a lack of bones structure. Attavante's art can therefore be seen as having a special place, and many points of contact with the artistic experimentations in techniques here outlined that, starting with Gentile da Fabriano, continued with Fra Angelico, Domenico Veneziano, Alessio Baldovinetti. In view of this, the sublime Benedictine fresco cycle of the so-called *Chiostro degli Aranci* (Florence, Badia) can be listed as another potential source for the representation and the 'literal' placement of dotted highlights in landscape details (Fig. 18). The complex reconstruction (Chiarini 1963) of the critical events linked to the attribution of this fundamental Florentine fresco cycle showed that Roberto Longhi was the first to ascribe it entirely to "Giovanni di Consalvo Portoghese" (João Gonçalves of Portugal), an artist recorded to be in Florence active alongside Fra Angelico's workshop in 1435, in his milestone account *Fatti di Masolino e Masaccio* (1940) [7].

The case of Attavante's 'miniaturized' graphic manner might not be a completely isolated trace of a figurative tradition taking inspiration from Baldovinetti's art; in fact, a case in this light it is found already in two full-page illustrations of the "*Divine*" *Comedy*, made in Florence (post-1458) for the so-called 'Pseudo-Boccaccio', the ms. Ricc. 1028 (Florence, Biblioteca Riccardiana) [8]. The good reputation accorded to this manuscript, starting with Luigi Rigoli's account (1829, Warren Vernon 1846), as a precious testimony of the work of letters done on the "*Divine*" *Comedy*, is very much of high impact, especially for the consideration given to the the two full-page pen drawings made as a decoration to this *Chiose* manuscript. Marisa B. Rotiroti (2008) has reported that the two folios presenting illustrations are additions posterior to the completion of the copy of the main text. The Ms. Ricc. 1028 is included among those manuscripts (about 130 in number) written in the so-called "scrittura mercantesca" (merchant handwriting), and among those non-professional copies of the several Commentaries on the "*Divine*" *Comedy* available in circulation, and on the market, as an act of testimony to the interest showed by the "minute people" for this text (Pomaro 1990). It is possible to identify the Ms. Ricc. 1028 with the *Chiose* belonging to the "Libreria Segni" (Branca 1958, Fig. 19), and particularly to Piero Segni, a Florentine erudite and Academic of the Accademia della Crusca known as 'Agghiacciato'. [9].

## 2.4 Between Italy and Portugal: luminous 'dots' and diaphanous 'atoms' in Cinquecento European Illumination

In her illuminating survey on the Florentine Miniature of the Renaissance, Annarosa Garzelli (1985) writes about the involvement of Attavante in the Medici patronage for the completion of humanistic codes. The artistic personality of Attavante is perfectly inscribed among the 'avant-gardist' of his epoch, for his works seem to recover both the tradition of the Florentine 'Flemish' fashion ('*fiamminghismo*', as showed in the Toledo, Ohio, *Madonna*), as well as that of copying and citing excerpts from contemporary grand-scale painting: "We have often [...] pointed out the ease shown by the miniaturist, and at the same time his interest in bringing occasionally on the illuminated page, though never for mere imitation purposes, not just the figurative excerpts, but entire works realized by the Florentine colleagues in the large dimensions." (Garzelli 1985). Just as Baldovinetti before him in San Miniato al Monte [10], Attavante was hired – possibly, with the favour of the Florentine merchants – to complete important artistic commissions for the Portuguese Royals. Attavante is, in fact, responsible for the decoration of the so-called *Lisbon Bible* (about 1494, Wohl 2017), made for Dom Manuel I, ruler from 1495 to 1521, and brother to Queen Eleanor of Portugal (1458-1525), in which he directly cites the Monument from the Chapel of the Cardinal of Portugal, Florence (Garzelli 1985, pl. 829).

Meanwhile, the miniaturist Antonio de Hollanda (about 1485 – 1557-58) is active at the court of Dom Manuel (1495-69, Bury 1984) and of his sister Eleanor, and he would have also worked later at the service of the Infante Dom Fernando, brother of João III [11]. Dom Fernando commissioned the decoration of the famous manuscript known as the *Portuguese Genealogy* for the Aviz House, initiated by Antonio in 1530, and completed by Alexander and Simon Bening. With exception for the figures, the designs made by Antonio de Hollanda have left a free hand for the display of the inventions made by Simon Bening, who has made use of golden threads in the borders (Ainsworth 2003).

Francisco de Hollanda, probably Antonio second-born son [12], in his treatise *Da Pintura Antigua* (I, 1548, XLIV- *Di tutti i generi e modi del dipingere*) and in his fourth *Roman Dialogue* (1548), describes his father's illumination as a new '*Miniaturmalerei*' – simultaneously developed in Italy by Giulio Clovio –, a very original miniature painting made of particular thin 'dots' called "atoms" ("Vi yo en las obras de iluminación de don Julio unos ciertos puntos que yo llamo atomos a manera de velos texidos, que parecen una niebla echada por encima de la pintura", de Holanda 1548-



, p. 106) that give to the parchment a certain veiled and smoky appearance, of admirable perfection and grace, worthy of praise such as the "great Tuscan manner" (Smith 1964) celebrated by Vasari and – in his view – totally accomplished with Michelangelo (Hirst 1988, Johannides 1992).

Francisco de Hollanda's account is – so far – the first written source with a critical comment, and a description of at least one among the various 'dotted' effects produced by Early, and Full Renaissance Masters, with a focus on book illumination. However, at the time it would not have been yet possible for him to elaborate a systematic approach in the distinguishing of the several 'dotted' manners put in operation in earlier art, such as those seen throughout the present study.

## 2.5 Conclusions

A fundamental connection between artists and their patrons active in Florence, and in Portugal – as well as in and from Flanders – is being highlighted in the present study, in order to 'map' the diffusion across Europe of dotted techniques in the decades here at issue. In light of this, a last clarification it is to be made with regard to the nature of the support for such objects as illuminated Manuscripts.

When speaking of dotted patterns in miniature painting and decoration, it is useful to distinguish whether the relief is actually effected by the *ready-made* nature of the support interacting with the figures depicted as flat, or instead by the actual visual definition and treatment of the forms represented, as it is the case with Attavante's decorations here discussed. In fact, as often in miniature art, the parchment can be "unneutral", for the background on which the illustrations are made appears as having already a "materialized" texture of its own. In some cases, so, the support is found as being articulated with a grain, and with 'points' texturizing the miniated page, showing properties that would have been later also advantageously used by Georges Seurat in his *frottage* technique paper works, made on *Michallet* sheets.

Nonetheless, what has been pursued and achieved by the Neo-Impressionists, and the Divisionists in the nineteenth century needs to be fairly distinct from the dotted pattern used and developed by fifteenth and sixteenth Century artists. The French chromoluminarists aimed at the scientific synthesis of color tones, following Chevreul's (1839), and the subsequent theories of simultaneously perceived colors, while in Early Masters' art the dots do not undergo a process of visual blending, nor serve as a pure means of coloring. They do coexist with the *disegno*, while enhancing the plastic qualities of the objects

depicted, reproducing their material interactions with the light.

To conclude, in the case of early art the colored spots do not neglect the image, nor act as its substitute. Yet, the similarities showed between the artists in the *procedimento* (method) attached to the creation of the color particles in the visual definition of an object are still fascinating. As it is pointed out in the present study, and with special regard to Baldovinetti's critical fortune, comparisons made between the visual properties of the colorism handled by early Masters, and the optical researches made in nineteenth century's luminism, have at least allowed for the rediscovery, and the general acknowledgement of the absolute degree of technical updating and experimentation occurred in early modern European art.

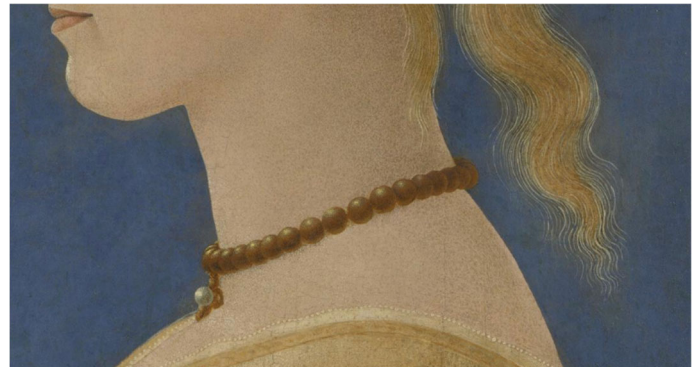


Fig. 1: Alesso Baldovinetti, *Portrait of a Lady*, about 1465, tempera and oil on wood, London, National Gallery, detail, © The National Gallery, London



Fig. 2: Giovanni di Paolo, *Entering of St. John the Baptist into the Wilderness* (from the "Butler" predella), 1454, egg tempera on wood, London, National Gallery, © The National Gallery, London





Fig. 3: Alesso Baldovinetti, *The Baptism of Christ* (from Fra Angelico, *The Silver Chest*), 1450-52, tempera and gold leaf on panel, Firenze, Museo di San Marco, detail, © Photograph taken by the author



Fig. 5: Alesso Baldovinetti, *The Feast at Cana* (from Fra Angelico, *Silver Chest*), 1450-52, tempera and gold leaf on panel, Firenze, Museo di San Marco, detail, © Photograph taken by the author



Fig. 4: Alesso Baldovinetti, *The Nativity*, 1460-62, mural painting, Firenze, Cloister "dei Voti", Chiesa della Santissima Annunziata, detail, © Photograph taken by the author



Fig. 6: Attavante degli Attavanti, *The Holy Trinity*, f. 1v, Ms. Cor. Laur. 4 (mm 700x500), color on parchment, 1505-6, Firenze, Biblioteca Medicea Laurenziana, detail, © Photograph taken by the author, with a special permission from the MiBAC. Any further reproduction by any means is strictly prohibited





Fig. 7: Alesso Baldovinetti, *The Holy Trinity and the Saints Benedetto and Giovanni Gualberto*, 1469-71, tempera on panel, Firenze, Galleria dell'Accademia, © Fototeca della Fondazione Zeri, Bologna



Fig. 9: Attavante degli Attavanti, *The Call of Peter*, f. 33v, Ms. Cor. Laur. 4 (mm 700x500), color on parchment, 1505-6, Firenze, Biblioteca Medicea Laurenziana, detail, © Photograph taken by the author, with a special permission from the MiBAC. Any further reproduction by any means is strictly prohibited



Fig. 8: Attavante degli Attavanti, *The Holy Trinity*, f. 1v, Ms. Cor. Laur. 4 (mm 700x500), color on parchment, 1505-6, Firenze, Biblioteca Medicea Laurenziana, detail, © Photograph taken by the author, with a special permission from the MiBAC. Any further reproduction by any means is strictly prohibited



Fig. 10: Attavante degli Attavanti, *The Feeding of the Multitude*, f. 43v, Ms. Cor. Laur. 4 (mm 700x500), color on parchment, 1505-6, Firenze, Biblioteca Medicea Laurenziana, detail, © Photograph taken by the author, with a special permission from the MiBAC. Any further reproduction by any means is strictly prohibited





Fig. 11: Giovanni di Paolo, *The Baptism of Christ* (from the "Butler" predella), 1454, egg tempera on wood, London, National Gallery, detail, © The National Gallery, London



Fig. 13: Alesso Baldovinetti, *The Annunciation*, 1466-68, mural painting, Firenze, Cappella del Cardinale del Portogallo, Basilica di San Miniato al Monte, detail, © Fototeca della Fondazione Zeri, Bologna



Fig. 12: Attavante degli Attavanti, *The Procession*, f. 7v, Ms. Cor. Laur. 4 (mm 700x500), color on parchment, 1505-6, Firenze, Biblioteca Medicea Laurenziana, detail, © Photograph taken by the author, with a special permission from the MiBAC. Any further reproduction by any means is strictly prohibited



Fig. 14: Attavante degli Attavanti, *The Cleansing of the Temple*, f. 56v, Ms. Cor. Laur. 4 (mm 700x500), color on parchment, 1505-6, Firenze, Biblioteca Medicea Laurenziana, detail, © Photograph taken by the author, with a special permission from the MiBAC. Any further reproduction by any means is strictly prohibited





Fig. 15: Alessio Baldovinetti, *Annunciation*, about 1457, tempera on oak board, Firenze, Galleria degli Uffizi, detail, © Photograph taken by the author



Fig. 17: Attavante degli Attavanti, *Prophet*, f. 1v, Ms. Cor. Laur. 4 (mm 700x500), color on parchment, 1505-6, Firenze, Biblioteca Medicea Laurenziana, detail, © Photograph taken by the author, with a special permission from the MiBAC. Any further reproduction by any means is strictly prohibited



Fig. 16: Attavante degli Attavanti, *The Cleansing of the Temple*, f. 56v, Ms. Cor. Laur. 4 (mm 700x500), color on parchment, 1505-6, Firenze, Biblioteca Medicea Laurenziana, detail, © Photograph taken by the author, with a special permission from the MiBAC. Any further reproduction by any means is strictly prohibited

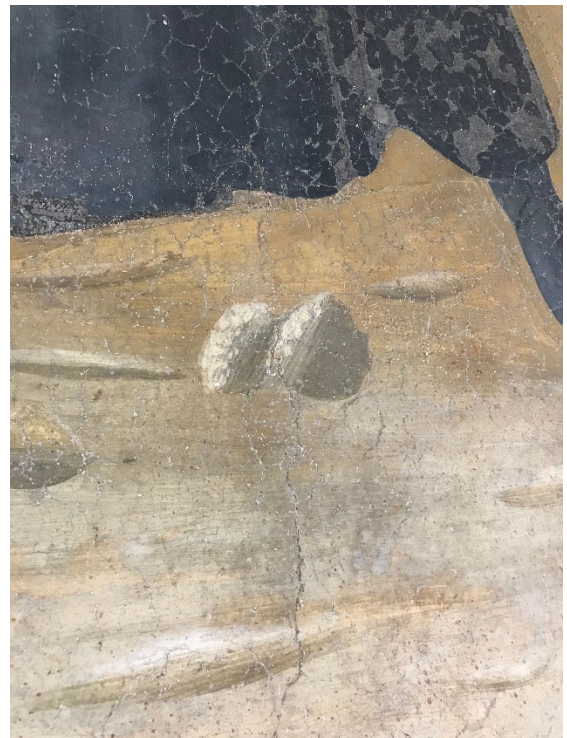


Fig. 18: João Goncalves, *Episodes from the Life of St. Benedict*, 1436-39, mural painting, Firenze, Badia Fiorentina, Chiostro "degli Aranci", detail of the western wall, © Photograph taken by the author



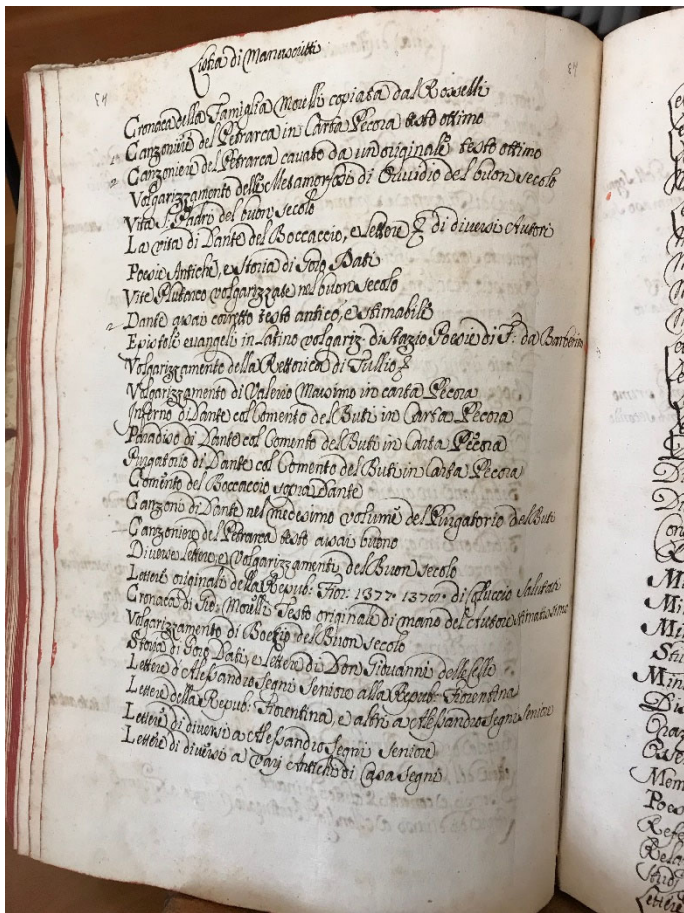


Fig. 19: Ms. Segni 7, f. 43r, Firenze, Biblioteca Medicea Laurenziana, detail, © Photograph taken by the author, with a special permission from the MiBAC. Any further reproduction by any means is strictly prohibited

### 3. Conflict of interest declaration

In my capacity as the only, and the corresponding author for the present article submitted to the Color Culture and Science Journal (CCSJ), I hereby declare that no financial/personal interests have affected the objectivity of the author, and that the present publication is not subjected to any potential conflicts of interest on the part of the author and the publisher.

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### 5. Author Biography

Carmen Di Meo, PhD, is an Art Historian based in The Netherlands. She is currently Course Instructor and Coordinator at the Faculty of Arts, Rijksuniversiteit Groningen. After her PhD (Roma 2017), she has been a Joint Post-Doc Fellow at the Department of Art History in Groningen, and a Visiting Research Fellow at the Netherlandish Institute in Florence (2018-2019).

### Notes

[1] A separate article is in preparation by the author of the present contribution in the proceedings from the symposium *The Skin of Things* (Amsterdam, 26-28 november, 2018), to present a detailed, and fully-developed account of the several readings of the Early Modern 'dotting' in association with a *pointilliste*-like fashion, and with different Modernist movements occurred in the course of the twentieth century. The paper draws upon the complete series of data, suggestions, and notes gathered together in order to propose an overall view, and a simultaneous interpretation of the whole fragments collected, in the art criticism, by the author in the course of her research on the topic. Hereafter, a list of major references discussing those associations is to be found: Grilli, G. (1903) 'Le Pitture Attribuite ad Alesso Baldovinetti in S. Miniato al Monte', *Rivista d'Italia, Lettere, Scienze ed Arte*, VI (1), pp. 156-165, 163; Londi 1907; Kennedy 1938; Brieger *et al.* 1969; Elam, C. (2019) *Roger Fry and Italian Art*, London: Paul Holberton Publishing, pp. 201-209. Also, the same is done about the presence of dotted patterns in the works of Flemish Art, in: Dunkerton, J. (1996/98) 'Observations on the handling properties of binding media identified in European painting from the fifteenth to the seventeenth centuries', *Bulletin- Institut Royal du Patrimoine Artistique*, 27, pp. 287-292, 287; Billinge, R. and Campbell, L. and Dunkerton, J. and Foister, S. and Kirby, J. and Pilc, J. and Roy, A. and Spring, M. and White, R. (1997) 'The Materials and Technique of Five Paintings by Rogier van der Weyden and his Workshop. National Gallery Technical Bulletin' 18, p. 82; Turner, N. K. (2006) 'The Suggestive Brush: Painting Techniques in Flemish Manuscripts from The Collections of The J. Paul Getty Museum and The Huntington Library', in *Flemish Manuscript Painting in Context* (Los Angeles, The J. Paul Getty Museum, 5-6 sept. 2003, and London, The Courtauld Institute of Art, 21 feb. 2004), Los Angeles: Getty Publications, pp. 57-74; Vandivere, A. (2017) 'Surface Effects in Paintings by Jan van Eyck', in *Van Eyck Studies, Proc. Eighteenth Symposium for the Study of Underdrawing and Technology in Painting* (Brussels 2012), Paris–Leuven–Bristol: Peters, pp. 417-433.

[2] It is known that Baldovinetti was appointed as keeper and restorer for the mosaics of the Florentine Baptistery (1487-1491, Vasari 1568), as well as that between 1420 and 1430 this extraordinary and incorruptible technique was restored back in Florence (Chastel 1954/55).

[3] The London *Portrait* was examined by Dr. Rachel Billinge (London, National Gallery of Art) with a stereomicroscope in 2008, and with the aid of photomicrographs and macro-photographs. In the yellow parts there are what look like tiny bubbles in the paint which may well be agglomerates of lead soaps formed by reaction of the binder with the pigment. While these are usually associated with oil paint, recent studies show that it is possible to encounter them in egg tempera paintings as well, for the free fatty acids in egg tempera also form metal soaps. For more information on the topic, see the abstract of the paper by Hale, C. and Arslanoglu, J. and Centeno, S. and Granacci, A. (2011) 'The Metropolitan Museum of Art: aspects of evolving workshop practice', Spring, M. and Howard H. (eds.), in *Studying old master paintings: technology and practice, Proceeding of The National Gallery Technical Bulletin 30th Anniversary Conference* (London 2011),

<[https://www.nationalgallery.org.uk/media/15375/conference\\_abstracts\\_studying-old-master-paintings.pdf](https://www.nationalgallery.org.uk/media/15375/conference_abstracts_studying-old-master-paintings.pdf)>, p. 17. As noticed also during the restoration works done on Fra Angelico's *Tabernacolo dei Linaioli*, it could be often possible at the time that the binder used to apply the gold leaf was yellow-tinged, to act as a yellow varnish simulating the appearance of gold. Bracco, P. and Ciappi, O. and Hilling, A.M. and Landi, L. (2011) 'La pittura del Tabernacolo dei Linaioli di Beato Angelico: osservazioni tecniche ed intervento di restauro', in Ciatti, M., and Scudieri, M. (eds.), *Il Tabernacolo dei Linaioli del Beato Angelico restaurato: restituzioni 2011 e A.R.P.A.I. per un capolavoro*, catalogue of the exhibition (Florence, Museo di San Marco, 22 march – 12 June 2011) Firenze: Edifir, pp. 101-142, p. 122. On a technical basis, tiny dots are also similarly visible in the works by Giovanni di Paolo.

[4] Among the Portuguese patrons involved in the San Miniato Florentine Chapel, it is found the Duchess Isabella of Burgundy (1397-1471), aunt of the young Cardinal and sister to the Infante Pedro, who had married Philip the Good in 1430, and had paid the sum of 600 florins for the Chapel between 1461 and the subsequent years (Apfelfadt 2000). Archival documents found in the records of the Cambini bank reported that the Pollajoli and Baldovinetti did not work on poplar panels – as of common usage in Florentine practice – but on 16 oak boards specifically brought from Flanders. (Hartt *et al.* 1964). A new launching of miniature art has occurred under the influence of Philip the Good (ruling from 1419 to 1467). Works of miniature art realized starting from 1445 for the Duke of Burgundy are, in fact, to be mainly ascribed to Rogier van der Weyden and to Jan van Eyck, with whom – and especially in the *Chroniques de Hainaut* – a new sense of perspective and of the landscape is perceived (Delaissé 1956).

[5] A thorough perusal of the Choir Books series from Santa Maria degli Angeli collected in the Laurenziana Library of Florence has been made by the author of the present study, for the purpose of this research, and as part of a NIKI Fellowship Program. A full detailed account of the story and the contents of the Choir Books from S.ta Maria degli Angeli and S.ta Maria Nuova is made in the ground-breaking studies by Kanter (1994), and by Levi d'Ancona (1993-94).

[6] Lionello Venturi writes, in fact, that "The female profiles made by Paolo [Uccello] are never made to reveal the bones structure. A modelling of the planes, where the anatomy is seen, is not a preference to the artist.". While discussing his reasons for eliminating the attribution of the London *Female Portrait* from the catalogue of Paolo Uccello's paintings, and viceversa in order to ascribing this to Domenico Veneziano, Venturi describes the (Baldovinetti) painting as such: "It is the work of an artist similar to Paolo, less imaginative and absolute, more delicate and raffinate [...]. The fable-air has disappeared, and it is already appearing a radiant reality". The two quotes have been translated by the author of the present study. (Venturi 1930, pp. 64-69).

[7] More about this fascinating cycle can be found in: Galassi, M. C. (2018) 'Osservazioni sulle tecniche di rappresentazione volumetrica: luci e ombre nella pittura fiorentina dei primi decenni del Quattrocento. Da Masaccio e Masolino agli esordi di Filippo Lippi', in: Lumen – Imago – Pictura, La luce nella storia dell'ottica e nella rappresentazione visiva da Giotto a Caravaggio, *Proc. International Conference* (Roma 2010), Ebert-Schiffner, S. and Roccasecca, P. and Thielemann, A. (Eds.), pp. 149 – 172, 158-159, De Luca Editori d'Arte, Roma; Bonavoglia, S. (1998) 'Ricordi Precoci del Luminismo di Jan van Eyck a Firenze: Alcuni Documenti per João Gonçalves e il Chiostro degli Aranci', *Arte documento*, 12, pp. 62 – 71, 66-67; Baldini, U. and Berti, L. (1958) *Mostra di Affreschi Staccati*. Catalogo della mostra, Firenze (Forte di Belvedere, 1958), pp. 41-44, Tipografia Giuntina, Firenze.

[8] In the Biblioteca Riccardiana of Florence, two copies of the text here examined survive, in the Manuscripts known as Ms. Ricc. 1028, and Ricc. 1037. This second version, signed as S.C., namely 'Secondo Codice' to be distinguished from the (first) 'Codice' (Ms. Ricc. 1028), has been

entirely copied and published in Florence, 1846, by Lord George John Warren Vernon. The Ricc. 1028 was cited by Giovanni Lami in his index as P. I num. XIX, and also registered in his 'Novelle Letterarie' of the year 1752 (Lami 1752). In the collection edited by Colomb de Batines (de Batines 1845, 1, pp. 231-232), an extensive study for this manuscript is to be found, in the second volume; here, also attention to the drawings is paid, although only for descriptive purposes (de Batines 1845, 2, p. 640-641, n735). A clear reference is made here to the presence of a lost third drawing also placed before the first 'Cantica' (Inferno), confirming so the information given by Salomone Morpurgo (Morpurgo 1900, p. 21). The manuscript is listed again in the two volumes by Vittore Branca, devoted to the 'Tradizione delle opere di Giovanni Boccaccio'. In the first volume is to be found the most interesting description of the codex, indicated as belonging – according to what was reported by de Batines (1845, 2, p. 640-641, n735) – to the "Libreria di Pier Segni", though mentioned in the section devoted to codes "out of reach" (Branca 1958). Other fundamental publications in this respect are: Kent, D. (2000) *Cosimo de' Medici and the Florentine Renaissance: the patron's oeuvre*. New Haven-London: Yale University Press, p. 420; De Robertis, T. and Miriello R. (eds., 1999) *I manoscritti datati della Biblioteca Riccardiana di Firenze*, II, Mss. 1001-1400. Tavarnuzze, Impruneta: SISMEL Edizioni del Galluzzo, p. 7; Branca, V. (1991) *Tradizione delle opere di Giovanni Boccaccio 2: Un secondo elenco di manoscritti e studi sul testo del "Decameron" con due appendici*. Roma: Edizioni di storia e letteratura, p. 12; Biagi, G. (ed. 1888) *Giunte e correzioni inedite alla bibliografia dantesca*. Colomb de Batines... Firenze: Sansoni, pp. 165, 230; VV. AA. (1865) *Esposizione dantesca in Firenze: Cataloghi*. Firenze: Le Monnier, p.27; Morpurgo, S. (ed., 1929) *Le opere volgari a stampa dei secoli 13. e 14. Supplemento con gli indici generali dei capoversi, dei manoscritti, dei nomi e dei soggetti*. Bologna: Zanichelli, p. 270. A very comprehensive enumeration of all the twenty codes available, containing the text of the so-called 'Falso Boccaccio' (dated back to 1375), is to be found in the study related to the first transcription and presentation of a text called *Memoria* (ms. Naz. II I 47, cc. 184r-189v), often added to the several copies of the *Chiose*, but excluded from the Ms. Ricc. 1028 (Mazzanti 2003). For a systematic study and an overall view of the production, and the forms of vernacular books in *Quattrocento* Italy see also Petrucci (2017). Finally, it was noticed by Salmi (1962) that "In Florence, Ghirlandajo's tendency which had a lasting influence over the etchings in printed books, stays totally excluded, in the miniatures and in the incunabula, from the tradition of the illustration of the Comedy [...]".

[9] This literary heritage belonged to the Segni family, a noble and ancient family of Florentine merchants, now part of the Collection of the Biblioteca Medicea Laurenziana, Florence. The Ms. Segni 7 contains a list of the Manuscripts possessed by the Segni (cc. 45v to 42r), the so-called *Index Manuscriptorum Codicum existentium in Bibliotheca familiae Segniae* (Bandini 1792); in the f. 43r is cited the 'Comento del Boccaccio sopra Dante'. The historical figure of Sir Piero Segni, member of the Crusca Academy since the 16<sup>th</sup> of August 1588, needs to be investigated further, since no relevant biographical information upon him are available up to date (Branca 1958; Benucci 2018). It is known that he has collaborated to the first editing of the Vocabulary of Italian language (1612), though he died years in advance, in 1605.

[10] For a complete account of Baldovinetti's involvement in this international commission, see the ground-breaking studies and documents here listed: Vasari, G. (1568) *Le vite dei più eccellenti pittori, scultori e architetti*, da Andrea Orcagna ad Andrea del Sarto, 4, (ed. 2014). Bagno a Ripoli (FI): Passigli, 4, p. 101; Zanobi, B. (1855) 'Alcuni documenti artistici non mai stampati: 1454 – 1565', Firenze: Le Monnier; Horne, H. P. (1903) 'A Newly Discovered 'Libro di Ricordi' of Alesso Baldovinetti', *The Burlington Magazine for Connoisseurs*, 2 (4), pp. 22-25+27-29+31-32; Horne, H. P. (1903) 'A Newly Discovered 'Libro di Ricordi' of Alesso Baldovinetti. Part II', *The Burlington Magazine for Connoisseurs*. 2 (5), pp. 167-171+173-174; Horne, H. P. (1903) 'Appendix: Documents Referred to in Mr. Herbert Horne's Articles on a Newly Discovered 'Libro di Ricordi' of Alesso Baldovinetti', *The Burlington*

Magazine for Connoisseurs, 2 (6), pp. 377-390. In order to framing here the several connections between Portuguese Aviz patrons, and the Tuscan artists, it can also be mentioned that the King John I called in Portugal Antonio Fiorentino, painter, who was still living in Portugal in 1438, as well as John II has later done with the Sansovino (Ruggieri Scudieri 1940, p. 94).

[11] It is plausible that a group of Flemish artists, coordinated by a follower of Gerard David, was active at the beginning of the sixteenth century in Évora, Portugal, in order to work at the twelve panels of the majestic retable with Episodes from the *Life of the Virgin* for the choir of the Cathedral (Ainsworth and Metzger 2009). More on this fascinating subject is to be found in: Goehring, M. L. (2007) 'The Representation and Meaning of Luxurious Textiles in Franco-Flemish Manuscript Illumination', in Rudy, K. M. and Baert, B. (eds.), *Weaving, Veiling, and Dressing: Textiles and Their Metaphors in the Late Middle Ages*, pp. 121-155; *Ead.* (2006) 'Taking Borders Seriously: The Significance of Cloth-of-Gold Textile Borders in Burgundian and post-Burgundian Manuscript Illumination in the Low Countries', *Oud Holland*, 119, 1, pp. 22-40.

[12] Francisco was born in Lisbon perhaps in 1518, and thanks to the renowned profession of his father, he inhabited the house of the Infant Don Louis, lover and patron of the arts, brother to the king João III, who succeeded to Don Manuel in 1521 (Battelli 1954). In 1537, Francisco de Hollanda leaves Portugal to live a few years in Rome, where he encountered Giulio Clovio (1538), Michelangelo and Vittoria Colonna, thanks to his personal commitment with the humanist Lattanzio Tolomei, his patron, legate of the Republic of Siena at the Papal Court, and friend to the Portuguese poet Francisco Sà de Miranda. After having visited other Italian cities such as Naples and Venice, around 1540-41 Francisco returned to Portugal, and in 1547, contemporaneously to the appearance of the first Italian translation of Alberti's *De Pictura* (Venice 1547), he wrote the first volume of his treatise *Da Pintura Antigua*. More about the commissions assigned to Antonio de Hollanda can be found in J. G. Alexander, J (ed.) (2009) *Il Lezionario Farnese*. Towneley Lectionary Manoscritto 91, New York, The New York Public Library, Astor, Lenox e Tilden Foundations. Modena: Panini, p. 11.

## References

Ainsworth, M. W. (2003) "Diverse Patterns Pertaining to the Crafts of Painters or Illuminators": Gerard David and the Bening Workshop', *Master Drawings*, 41, 3, pp. 240-265.

Ainsworth, W. M. and Metzger, C. (2009) 'The Évora Altarpiece, A Preliminary Report', in Verougstraete, H. and Janssens de Bisthoven, C. (eds.) *The Quest for the Original, Underdrawing and Technology in Painting* (Symposium XVI, Bruges, September 21 – 23, 2006), Leuven: Peeters, pp. 10-20.

Ames-Lewis, F. (1984) 'Matteo de' Pasti and the Use of Powdered Gold', *Mitteilungen des Kunsthistorischen Institutes in Florenz*, 28, p. 352.

Apfelfadt, E. (2000) 'Bishop and Pawn: New Documents for the Chapel of The Cardinal of Portugal at S. Miniato al Monte, Florence', in Lowe, K.J.P. (ed.) *Cultural Links Between Portugal and Italy in the Renaissance*, New York: Oxford University Press, pp. 183-205, p. 198, n68.

Argan, G. C. (1970) *L'arte moderna, 1770-1970* (ed. 2002), Milano: Sansoni editore, pp. 45-46.

Bandini, A. M. (1792) *Bibliotheca Leopoldina Laurentiana, seu Catalogus manuscritorum qui iussu Petri Leopoldi... Tomus secundus*, Firenze: Florentiae Typis Regiis, 1792 p. 226.

Bartalini, R. (1990) 'Alesso Baldovinetti', in Bellosi, L. (ed.) *Pittura di luce: Giovanni di Francesco e l'arte fiorentina di metà Quattrocento*, (Firenze,

Casa Buonarroti, 16 maggio – 20 agosto 1990), Milano: Olivetti – Electa, pp. 159-169, 162-163.

Battelli, G. (1954) 'La Roma di Francisco D'Ollanda', *Studi Romani*, V, pp. 536-540.

Bellosi, L. (2000). 'Come un prato fiorito: studi sull'arte tardogotica'. Milano: Jaca book, p. 108.

Benucci E. (2018) 'Gli accademici compilatori del primo Vocabolario. Novità e questioni ancora aperte', in Belloni G., and Trovato P. (eds.) *La Crusca e i testi: Lessicografia, tecniche editoriali e collezionismo librario intorno al Vocabolario del 1612*. Padova: [libreriauniversitaria.it](http://libreriauniversitaria.it) edizioni, pp. 306 n18, 313-314, 319.

Biblioteca Riccardiana (2012) [http://www.riccardiana.firenze.sbn.it/colorionLAB/page.php?segn=Ricc.1028&trova=1&suffisso=1&segnatura=&autore=&data\\_search=&localizzazione=&miniatura=&tipologia=&tecnica=&ricerca\\_libera=&ancora=215](http://www.riccardiana.firenze.sbn.it/colorionLAB/page.php?segn=Ricc.1028&trova=1&suffisso=1&segnatura=&autore=&data_search=&localizzazione=&miniatura=&tipologia=&tecnica=&ricerca_libera=&ancora=215).

Boschi Rotiroti, M. (2008) *Censimento dei manoscritti della Commedia*, Firenze, Biblioteche Riccardiana e Moreniana, Società Dantesca Italiana. Roma: Viella, pp. 48-50, 48.

Branca, V. (1958) *Tradizione delle opere di Giovanni Boccaccio 1: Un primo elenco dei codici e tre studi*. Roma: Edizioni di storia e letteratura, p. 19.

Brandi, C. (1941) 'Giovanni di Paolo (I)', *Le Arti*, III, 4, pp. 230-250, 230.

*Id.* (1941) 'Giovanni di Paolo (II)', *Le Arti*, III, 5, pp. 316-341, 333.

Brieger, P. and Meiss, M. and Singleton, C. S. (1969) *Illuminated Manuscripts of the Divine Comedy*. Princeton: Bollingen Foundation – Princeton University Press, pp. 75-76.

Bury, J. B. (1984) 'Francisco de Holanda and His Illustrations of the Creation', *Portuguese Studies*, 2, pp. 15-48.

Chastel, A. (1954/55). 'La mosaïque à Venise et à Florence au XVe siècle', *Arte veneta*, 119 – 130, 123-124.

Chiarini, M. (1963) 'Il Maestro del Chiostro degli Aranci: Giovanni di Consalvo Portoghese', *Proporzioni*, 4, pp. 1-24.

D'Ancona, P. (1910) 'Un'opera ignorata di Attavante degli Attavanti nella Biblioteca Corsiniana di Roma', *Rivista d'arte*, 7, pp. 113-123, 122.

D'Ancona, P. (1914) *La miniatura fiorentina: secoli XI – XVI*, 2, Cat. descrittivo, Firenze: Olschki, pp. 755-758.

de Batines, C. (1845) *Bibliografia dantesca, ossia Catalogo delle edizioni, traduzioni, codici manoscritti e commenti della Divina Commedia e delle opere minori di Dante, seguito dalla serie de' biografii di lui*, voll. 2. Prato: Aldina Editrice.

de Holanda, F. (1548-) 'Diálogos de la pintura', in Sánchez Cantón, F. J. (ed. 1923) *Fuentes literarias para la historia del Arte Español*, I, Madrid: Imprenta Clásica Española, pp. 35-124, p. 106.

de Hollanda, F. (1548-) *I trattati d'arte*, Modroni G. (ed.). Livorno: Sillabe, p. 95.

Delaisé, L. M. J. (1956) *La miniatura fiamminga al tempo di Filippo il Buono*. Milano: Electa editrice, pp. 7-25.

Fry, R. E. (1911) 'On a Profile Portrait by Baldovinetti', *The Burlington Magazine for Connoisseurs*, 18 (96), pp. 308+311-313, 311-12.

Garzelli, A. (1985) *Miniatura fiorentina del Rinascimento (1440-1525): un primo censimento*, I. Scandicci: La Nuova Italia Editrice, pp. 232-235.

Gengaro, M. L. (1932) 'Ecclettismo e Arte nel Quattrocento Senese: Giovanni di Paolo', *La Diana: rassegna d'arte e vita senese*, VII (1), pp. 8-33, 13.

- Hartt, F. and Corti, G. and Kennedy, C. (1964). *The Chapel of the Cardinal of Portugal 1434-1459 at San Miniato in Florence*, Philadelphia, University of Pennsylvania Press, pp. 150, 157.
- Hirst, M. (1988) *Michelangelo and His Drawings*. New Haven: Yale Univ. Press, p. 112.
- Huetter, L. (1940) 'Orme di Portoghesi in Italia', in *Relazioni storiche fra l'Italia e il Portogallo: memorie e documenti*, Roma: Reale Accademia d'Italia, pp. 489-510, 493.
- ITA-ACCRU-AU-275, Catalogo in rete degli Accademici della Crusca, <http://www.accademicidellacrusca.org/scheda?IDN=275>, Segni, Piero.
- Joannides, P. (1992) ' "Primitivism" in the Late Drawings of Michelangelo: The Master's Construction of an Old-Aged Style', in Smyth, C. H., and Gilkerson, A, *Michelangelo Drawings, Proceedings from the Symposium (Washington DC, CASVA, 7-8 october 1988)*, Hanover: Univ. Press of New England, pp. 245-261.
- Kanter, L. B. (1994) 'The Illuminators of Early Renaissance Florence', in: *Painting and Illumination in Early Renaissance Florence, 1300-1450. Catalogue of the Exhibition (New York, Metropolitan Museum of Art, nov. 17, 1994 – feb. 26, 1995)*, New York: Abrams, pp. 3-13.
- Kennedy, R. W. (1938) *Alesso Baldovinetti: A Critical and Historical Study*. New Haven: Yale University Press, pp. 14, 20, 39-41, 81-87.
- Lami, G. (1752) 'Novelle letterarie pubblicate in Firenze l'anno 1752', Firenze: Stamperia Imperiale, coll. 324-327, 447-453, 479-482.
- Levi d'Ancona, M. (1993-94) *The Illuminators and Illuminations of the Choir Books from Santa Maria degli Angeli and Santa Maria Nuova in Florence*. Firenze: Centro Di, p. 179.
- Levi d'Ancona, M. (1995) 'Gli artisti di Santa Maria degli Angeli e le loro miniature', in: *I corali del monastero di Santa Maria degli Angeli e le loro miniature asportate. Catalogo della mostra (Firenze, Biblioteca Medicea Laurenziana, 15 june - 31 july 1995)*, Firenze: Centro Di, pp. 111-193, p. 176, 179.
- Londi, E. (1907) *Alesso Baldovinetti, pittore fiorentino: con l'aggiunta dei suoi "Ricordi"*. Firenze: Alfani e Venturi.
- Longhi, R. (1927) *Piero della Francesca, con aggiunte fino al 1962 (ed. 1963)*. Firenze: Sansoni, pp. 36, 65.
- Id.* (1940). 'Fatti di Masolino e Masaccio', *Critica d'arte*, 5, pp. 145-191.
- Mazzanti, F. (2003) 'La Memoria di Quatuordecim Valentissimi Homini Romani: un inedito e sconosciuto frammento del Falso Boccaccio', *Rivista di Studi Danteschi*, 2, p. 443 n2.
- Morpurgo, S. (1900) 'I manoscritti della R. Biblioteca Riccardiana di Firenze: Manoscritti italiani', 1, in: *Indici e Cataloghi (15)*, Roma: Ministero dell'Educazione Nazionale.
- Petrucchi, A. (2017) *Letteratura italiana: una storia attraverso la scrittura*. Roma: Carocci, pp. 186-190.
- Poggi, G. (1909) *Ricordi di Alessio Baldovinetti, nuovamente pubblicati e illustrati*. Firenze: Libreria Editrice Fiorentina.
- Pomaro, G. (1990) 'Codicologia Dantesca I. L'Officina di Vat.', *Studi Danteschi*, 58, p. 352 n30.
- Ruggieri Scudieri, J. (1940), 'Primi contatti letterari fra Italia e Portogallo fino a Sá de Miranda', in: *Relazioni storiche fra l'Italia e il Portogallo, cit.*, pp. 91-112.
- Salmi, M. (1962) 'Problemi figurativi dei codici danteschi del Tre e Quattrocento', in: *Atti del Congresso Internazionale di Studi Danteschi*, Firenze: Olschki, p. 181.
- Smith, W. (1964) 'Giulio Clovio and the 'Maniera di Figure Piccole'', *The Art Bulletin*. 46, pp. 395-401.
- Thieme, U. and Becker, F. (1966) *Allgemeines Lexikon der bildenden Künstler von der Antike bis zur Gegenwart*, 12, Leipzig: Seemann 1, p. 332.
- Venturi, L. (1930) 'Paolo Uccello', *L'arte*, 33, pp. 52-87.
- Warren Vernon, G. J. (1846) *Chiose sopra Dante*. Firenze: Piatti.
- Wohl, A. S. (2017) 'The Lisbon Bible and the Throne of Portugal', *The Burlington Magazine*, 159 (1366), pp. 14-24.



# Two theories for a model: the “querelle” between Klee and Ostwald

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## ABSTRACT

Framed in the time of history, the comparative theories of colour expressed not only give us a sort of "distillate" of chromatic culture, but also constitute a precious instrument of investigation, useful in the syncretic comparison of thoughts and positions, sometimes very different from each other, as in the case of the "querelle" between Paul Klee and Wilhelm Ostwald, a question proposed here again. This type of comparison, addressed in the 2017 conference on circular models, is developed here on biconical models, starting with those of Wilhelm Ostwald and Paul Klee, assuming and confirming the classification and analytical structuring of the models through the parameters adopted in Polychrome (Marotta 1999). It should be remembered that Klee publicly took a stand against Ostwald's theory and his model, but in fact assumed the essential geometry of the model of the chemist himself. The present investigation therefore aims to better clarify (in the face of formal analogies) the differences in objectives and scientific and artistic content. The work confirms that the position taken by Klee and his followers was partly prejudicial, linked to his artistic training and related experiences in the field, to which his intellectual milieu was no stranger. The position of the chemist is symmetrical, linked to the rigor of his scientific profile (although completed by the practice of painting). The substantial rapprochement of their respective convictions confirms the open-mindedness and maturity to which the two protagonists have arrived. In addition to describing cultural matrices, parameters and essential characteristics of the models examined, of particular interest is the scope of the applications already put in place of the models, or possible future developments, also connected to new methodologies (such as virtual and digital) in the color project, up to the experiments in concrete and material production. The most innovative digital virtual modes will allow to verify the analogies and differences (of forms and contents) of the respective models.

**KEYWORDS** Comparative theories of colour, Colour models, Paul Klee, Wilhelm Ostwald, History of colour, Polysensory

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## 1. Introduction

The synoptic picture of the models, which over time invert and represent the relative theories of colour, crystallizes (through images) a syncretic process in which the same theories have been produced and transformed.

The comparison - also formal - of thought through chromatic models (Marotta 1999) confirms its usefulness, even in the speculations sustained and represented by digital. In confirmation of this, a significant case could be constituted by the comparison - still under development - between the theories of Paul Klee and Wilhelm Ostwald and their respective visualizations (both with a double cone configuration), between analogies and differences. The present contribution should therefore be considered as an investigative phase, preliminary to more precise applications and investigations through advanced technologies, now underway.

From a consolidated and "static" situation, contemporary reality leads us to new experimentations to decline virtual and digital modes, also in the chromatic field. This type of comparison, (dealt with in the XIII Conference of Colour on circular models (Marotta 2017)), will be developed on biconical models, starting from Ostwald's and Klee's, assuming and confirming the classification and analytical structuring of the models through the parameters adopted in Polychrome (Marotta 1999). The most innovative virtual and digital modes will allow to verify the analogies and differences (of forms and contents) of the respective models. It should be remembered that Klee publicly took a stand against Ostwald's theory and his model, but in fact assumed the essential geometry of the model of the chemist himself. The present study therefore aims to better clarify (in the face of formal similarities) the differences in scientific and artistic objectives and contents.

In fact, in the Bauhaus of the early 1920s, the apparent rejection of the material aspects of colour may have originated not only from the mystical tendencies of the School, but from more concrete factors (Geelhaar 1972). At the root of the "querelle" between Klee and Ostwald, it should be remembered that Itten's master, Hoelzel, was a declared opponent of the chemist's theory of colours. Of the latter, we recall that in 1909 he was awarded the Nobel Prize for his research in physical chemistry, a discipline he invented himself. An amateur painter, accustomed from childhood to preparing pigments, Ostwald developed a deep interest in colour in all its aspects. A tenacious (and amateur) painter, he spread his theories in the firm belief that there were absolute colour principles for art, to which he himself adhered: not following them led to the creation of works that were not "correct". He was in open disagreement, therefore, with freer artists and less strictly bound to his theories, consistent also with the socialist

convictions of the time. Some critics, such as Max Doerner, mocked the chemist: "To painters it seemed quite amusing that Professor Ostwald, analyzing Titian, announced that the blue of a cloak was two tones too high or too deep! It was simply Titian's typical blue."

## 2. Confirmations and denials of a heated and broadened debate

Klee's theoretical and speculative activity is also rich in acute annotations (still relevant today), many in the psychological field (Cherchi 1978), when he states: "even space is a temporal notion [...]. In the work of art there are paths prepared for the eye of the spectator, who is about to explore, as an animal grazing in a meadow (in music as we know, channels guide the ear, while the theater combines the two possibilities). [...]. The musical work has the advantage of being perceived exactly in the order of succession in which it was conceived (Klee 1920). Even today, the instrumentally recorded path of the pupils who "palpitate" in the analysis of eye trekking is the most current scientific response to what Klee observed during his lessons at the Bauhaus: "music evokes spaces but does not possess them. While it is possible to construct visual itineraries in front of a painted canvas and the eye can in turn return to the starting point, hurry towards the boundaries of the surface and stop at will in any of the chosen areas, the ear is instead dragged forward by the music and its only resource to order the impressions, is to appeal to memory" (Klee 1956).

It is hardly necessary to stress how the relationship between sound and colour (in Klee as in Kandinsky) is never only synaesthetic, that is to say limitedly aimed at evoking or representing sensory experiences, also covering rhetorical purposes up to symbolic functions (Marotta 1999).

The strong matrix, common to the two artists, must be recognized in the conception of the wide and articulated circularity and interpenetration of all the arts, all understood with a single objective: the promotion of spiritual values in a world to be reconstructed, especially after the Great War of 1914-18. The Canon of the Chromatic Totality, a model developed by Klee, can assume in this sense a significant value of cosmic totality. It is then demonstrated how wide and elevated are the connections between terms such as "voice, canon, chord", also borrowed from the musical vocabulary: "Each colour starts from its own nothing, that is from the top of the near colour, first slowly and then more and more growing until it touches its own top; it then slowly decreases, towards its own nothing, that is towards the top of the other adjacent colour. But there's still something: on the record the

colours don't sound with one voice, as it might seem from the chain, but in a sort of three-voice chord. This representation is designed to show us the three-voice movement and to follow the process. As a canon, the voices attack each other one after the other; in each of the three main points a voice culminates, another voice begins to play slowly and another one is lost. This new figure could be called the canon of totality" (figs. 1 and 2) (Klee 1956). Visually comparing Ostwald's double-cone colour model with Klee's *Canone della Totalità Cromatica* (illustrated, among other things, in a lecture at the Bauhaus on 19 December 1922), it is impossible not to grasp the formal derivation of the Kleean figure from the Ostwaldan figure. Both models have a double-cone structure: at the ends of the vertical axis there are respectively white and black, while on the central section, at the intersection of the two cones, there is the chromatic circle. In Ostwald's model, the pure colours, arranged around the circumference of the circle, can be six, twelve, twenty-four or more, with the respective complementary colours (always diametrically opposed) located in circular sectors of equal size; while in Klee's Canon of Totality only three basic colours are indicated, arranged around the centre of the double cone, with a much sharper spiral pattern, a figure considered by the Author as an emblem of perfect geometric and dynamic synthesis. The above considerations confirm the derivation from Ostwald of Klee's Canon of Total Chromaticity, which functionally adapts the model of the German chemist - although he does not share the rigid and static approach - to the expression of dynamic colour, according to his own convictions.

From the comparison, and also taking into account the chronology, one can legitimately assume that Klee derived from Ostwald the setting for his Canon of the Chromatic Totality, considering it adequate, functional to the expression of the movement of the colour he studied ("red in red, in other words the scale of red diluted to deep red, in all its extension or partially") although he does not share the precise "science" of Ostwald, Klee does not accept his ideas on the harmonic accord of colours (Ostwald 1922).

However, the Bernese does not miss an opportunity to underline the diversity of his approach: in the lesson dedicated to order in the field of colours, held at the Bauhaus on 28 November 1922, the Swiss Master recalls that: "there are, as is well known, many theories of colors. For example, we have Goethe's theory, which was created to refute Newtonian statements". It is the most exhaustive treatment of his time on the physiological, physical and chemical aspect of colors. The author continues, "A chapter is also devoted to the sensitive-ethical effect of colours. More ancient traces of a theory of the colours of painting can be found in Leonardo, Dürer and others. Now

other colour theories have also been formulated; today two are being discussed: Hoelzel and Ostwald; but we are not a colour industry or a chemical dyeing plant, we must be free and have all the possibilities at our disposal". The importance - attributed by the artist from Bern to the psychological component and instead neglected by the "men of science" (here it is not by chance that Klee insists on repeating the reference to Ostwald) - is certainly a decisive argument of Klee's dissent: "those who study colours from a scientific point of view are generally concerned with providing logical-mathematical evidence. And so, the psychological aspect is neglected; as Ostwald does, for example (Birren 1969). The psychology of the painter requires the division of the circle into three and in six  $1/6$  is a number more akin to the circle than  $1/8$ ". (Klee 1956). Klee's criticism of the limits of a purely technical-chemical orientation that "quietly neglects all transparent mixtures (veils)", and that shows a "complete ignorance of the relativity of chromatic values", thus becomes evident and takes shape. On the basis of this, the assumption of "harmonizing" by means of a tonality of equal value is considered reductive, since it would mean "renouncing all psychic richness" - thus visualized in the tone variations - limiting the artist's own freedom.

It would mean, in essence, not rendering the "gradations, from the smallest movement to the rich flowering of chromatic polyphony" (Klee 1956). To confirm Klee's position against that of Ostwald, it should be remembered that, by illustrating his theory of colour, the Swiss painter reiterates that he instead drew on theories of artists, which he explicitly recalls: "I want to try to tell you something useful about colour. I don't just base myself on my research, but I take ideas from others, men of science and not, with a light heart, to give them back to you. To name a few, I remember Goethe, Philipp Otto Runge, Delacroix, Kandinsky". On the contrary, the reference to some "men of science" is more general, but it is not by chance that Wilhelm Ostwald is mentioned among them. Regarding his theory, Klee writes, in a letter to Hans Hildebrandt: "What most artists have in common, the aversion of color as a science, became understandable to me when, a short time ago, I read Ostwald's theory of colors. But I wanted to take some time to see if I could get something good out of it. Instead, I only managed to extract a few curiosities. First of all, the pedestrian claim that acoustic science has stimulated music production. So, the reference to Helmholtz-Ostwald parallelism in their negative relationship to the arts would be quite correct. But that's not what they allude to. Scientists often find something childish in the arts. But in this case the positions are reversed. Puerili are also other things, for example the conception of a Potsdam square in which cars circulate honking their horn with a chord of do sharp. That could be

funny, apart from the harmful practice whereby this uniform chord, this sound image without dissonances would be musical. His ideas on the harmonic chord of colours are also devoid of dissonances: the result is sounds comparable to the jodler and the Gstanzler. Because it is an old story that beauty combined with beauty gives an insipid result. Very strange also the idea that the temperate chord in music is the work of science. I can only see it as a practical help. An analogous help is the scale of the chemical industry of the colors. Of course, we've been using it for a long time, but we don't need a colour theory at all. All the infinite mixtures never produce Schweinfurt green, a saturated red and a cobalt violet. In our country a dark yellow is never mixed with black because otherwise it gives the green. In addition, the chemistry of colours quietly overlooks all transparent mixtures (glazes). Not to mention the complete ignorance of the relativity of the chromatic values. To believe that the possibility of harmonizing by means of a shade of equal value must become a general rule is to renounce all psychic richness. Thank you very much!" (Klee 1956). In the Bauhaus years (but also in the decades that followed), like Klee and Kandinsky, Johannes Itten also rejected Ostwald's double cone approach: "When he establishes the equation 'Harmony = Order' - he contests - and gives the circle of colour of equal shade and the triangle of colour of similar value (saturation) as an example of order, he neglects the psychological laws of simultaneity and posthumous effect", demonstrating how convinced he was of the need for an interpretation of colour in a strongly psychological key, in this case gestalt (Marotta 1999).

More generally, the attention - even if indispensable - to the theoretical contributions matured at Bauhaus and privileged here, must not overlook more experimental findings and outcomes of the chromatic theories themselves. Alongside the already mentioned applications of Klee and Albers (Albers 1962) (in the field of glass painting) or of Kandinsky (for fresco techniques), numerous experiences have developed from the same theories, inside and outside the laboratories of the School. Here we can remember the examples in the Atelier of decoration for interior architecture, directed by Hinnerk Scheper, or the architectures - in the manifestations of the neoplastic movement - decomposed according to chromatic planes, by Theo Van Doesburg and Gerrit Thomas Rietveld, by Pieter Oud and Ludwig Mies Van Der Rohe. Or, architectural projects inspired by the same principles, by Herbert Bayer, Alfred Arndt, Farkas Molnár. The same applies to the textile workshops (with the contribution and work of artists such as Anni Albers and Güntra Stoltz), graphics (with figures such as Herbert Bayer) and children's games: the toys developed at the Bauhaus, not being a perfect imitation of objects from the

adult world, were to stimulate the child's imagination, allowing him to set in motion the infinite possibilities of composition and free reproduction of objects. Ludwig Hirschfeld-Mack, with his colorful spinning top, particularly enhances the educational aspect. Wingler notes in particular: "On the rotating spinning top, cardboard discs with printed segments in different colours or eccentric coloured circles could be thrown onto the pole. The rotation movement gave rise to an optical mixture of colours. This demonstrated, among other things, Goethe's, Schopenhauer's and Bezold's theories of colour" (Wingler 1962, Zevi 1974).

### **3. Klee and Ostwald. Comparison of chromatic theories**

We can once again confirm that - at the Bauhaus - Itten's thought (Itten 1962) contrary to Ostwald's theories was shared with similar intensity by Klee: although as a young man, in 1904, he was one of the few artists to express enthusiasm for Wilhelm Malerbriefe's manual (Letters to a Painter), calling it "an excellent scientific treatment of all technical subjects", later his opinions changed radically, as we have already mentioned, in the aforementioned letter to Hildebrandt (Klee 1956, Cherchi 1978).

#### **3.1 Wilhelm Ostwald. The fate of a chemist, Nobel laureate and artist**

As we have already mentioned, the theoretical principles that Ostwald (Marotta 1999) enunciates, carrying out chemical experiments and expressing important considerations on colors, have been strongly opposed by artists such as Itten and Klee. The Double Cone, his model of color, created - it seems between 1915 and 1919 - has a vertical axis, on which is the scale of grays (from white to black) and the central section (equator) on the plane of intersection of the two cones, on which is placed the chromatic circle. This visualization stems from his conviction that the colours included in the circle of pure colours, when mixed with white or black, differ little from each other.

After graduating from Dorpat University, he taught at the Riga Polytechnic in 1881, at the University of Leipzig in 1887 and then in 1898 became director of the Institute of Electrochemistry in the same city. He is best known for his work on electrolytes and catalysis. In 1888 he applied the law of mass action to the ionization of electrolytes, discovering the law of dilution that bears his name and that will give a decisive impulse to the progress of this field of research; the first law allows to calculate the constant dissociation of an acid or a weak base through the measurement of the conductivity of their solutions; the second states that when a liquid in the cooling phase can,

by solidifying, assume a stable or metastable form, it generally solidifies in the first time in the metastable form.

In 1907 he developed the industrial preparation of nitric acid by catalytic oxidation of ammonia (Marotta 1999). His studies on catalysis earned him the Nobel Prize for chemistry in 1909. He also deals with topics of a philosophical nature, interests that led him to find the "Annalen der Naturphilosophie". He was one of the first ardent advocates of energyism, a doctrine that, in opposition to mechanical materialism, denied the need to base physics on the idea of matter and on atomistic hypothesis in particular, considering the concept of energy as fundamental, to which the explanation of every physical phenomenon can be traced. Ostwald considers energy as a sort of metaphysics where energy takes on the role of first principle, source of all the forces of nature. The overcoming of scientific materialism (*Die Ueberwindung des wissenschaftlichen Materialismus*, Leipzig 1895), opens a bitter controversy that will long oppose materialists and energetists. However, already at the beginning of the new century, his conceptions appeared to be surpassed by the numerous confirmations that the atomistic hypothesis received in every sector of physics. In his *Manual of Colours (Die Farbenfibel)* (Ostwald 1922) he expresses himself as follows: "Experience teaches that certain juxtapositions of colours produce a pleasant effect, others an unpleasant or indifferent effect. The problem of why arises. The answer is: colors that are in a precise and regulated reciprocal relationship, that is, in an order, produce a pleasant effect. If this is missing, the colours appear unpleasant or indifferent. The groups of colours that produce a pleasant effect are called harmonic and we can therefore establish the fundamental principle: harmony = order. In order to find all possible forms of harmony we must explore all possible ways of sorting the colors. The simpler the order is, the more evident and obvious is the harmony. Of all the orders, two seem to us to be fundamental, that is, the disc of equivalent colours (having the same brightness or darkness) and the triangle of identical tonal values (that is, the combinations of a colour with white or black). Discs produce harmonies of different tones, triangles, harmonies of the same value" (Marotta 1999).

### 3.2 Paul Klee, the destiny of a multiform and multifaceted artist

In Klee's investigations (Marotta 1999) one of the themes of interest is the manifestation of visual forms in the plane (dynamically conceived and expressed), also in relation to spatial dimensions. The forms that make up an image have a different incidence, depending on their brightness, size and chromatic character and can (must) be organized in a balanced composition.

In particular, his discovery of colour took place on the occasion of his trip to Tunis in 1914 (a circumstance partly overestimated by many critics), as evidenced by the notes in his diary where he wrote, among other things: "We have become one with colour". In 1922 he created what he called the Canon of Totality (fig. 2) inspired in some way by the circle generated by the section of the Runge sphere, with the intermediate and universal grey and the two poles white and black. Klee tries to visualize the dynamic quality of colour through a spiral movement - his favourite form - that transmits with its development the energy of colour on the circumference, while diametrically the chromatic pairs are harmonized by the grey that "fluctuates" in the centre.

Born into a family of musicians, from whom he inherited a great passion for music and in particular for the violin, after high school in Bern, Klee studied painting for three years at the Academy in Munich. In these years he received a teaching based on the rigor of the hatching and on a realism respectful of the proportions. He studied anatomy and art history and already in 1902-03 he expressed a highly plastic, grotesquely caricatured style. Around 1909 he moved on to a graphic phase characterised by a nervous touch, accentuated dynamism and the subtlety of the figures. The first exhibitions in Switzerland and Munich date from this period. After 1912, he devoted himself to the reworking of French models such as those of Cézanne and Delaunay, frequenting exponents of the *Blaue Reiter*. In 1914 he made his trip to Tunisia: the suggestions and naturalistic notes that he drew from them helped to direct him towards daring lighting solutions. The works of this period are characterized by programmatically two-dimensional formal configurations, frequent symbolic allusions and the introduction of a lyrical, ironic, humorous note in the title of the paintings. Until after 1920, subtle articulations of lines, scribbles, representing men or animals pervaded by a violent dynamic tension, predominate in his works. Increasingly he uses combinations of parallel lines, with circumferences that recall wheels connected to transmission belts, arrows, heart-shaped motifs, ships and finally, horizontal lines on which the structures seem almost strung. A particular meaning also has the presence of numbers, letters or words: a module of Cubist collages, which in Klee constitute the link between the spirituality of thought and its realization rationally controlled, plastic, characterizing the pictorial invention as a poetic expression.

This formal freedom will be accompanied in oils, watercolours and tempera by a definitive conquest of the chromatic dimension. From the time he travelled to Tunis, Klee began to coordinate delicately luminous coloured surfaces, before using colour as an element of a fantastic narrative: dark, often dark fields, from which clear luminous motifs or graffiti drawings are detached. Around



the twenties, Klee experimented with a very different and articulated use of colour, applied in relation to the greater or lesser weight of the contours, with their dynamics and expressive force: a choice certainly linked to the didactic activity carried out at the Bauhaus. This new conception of colour is accompanied by the writing of theoretical writings, through which Klee intends to communicate his vision of art. In 1924, during a lecture at the Kunstverein in Jena, he explained that the different functions in the different realms of nature lead to vital irregularities, reiterating (in accordance with the principles of Gestalt) that the artist must deal with the dimensions of mass (line), weight (tonality) and quality (color), not verisimilitude and must aim not at an external model, but at the original theme, the principle of creation, where the key to everything lies. On the other hand, in a note Klee argued that the figure is a living being, it is nature, because his theory of figuration (Gestaltung) deals with the ways that lead to form. Saying: "theory of formation" is unusual, therefore, compared to form, figure (Gestalt) expresses something more alive. The figure is a form based on vital functions and these functions are of a spiritual nature, their basis is the need for expression. To pass from a form to a figure - he maintains - creative force is necessary, which therefore cannot be defined: there is matter and reason". In addition to this, the choice of means is important: over the material means (wood, metals, glass) it is preferable to use the ideal means (line, chiaroscuro, color): writing and image (Klee 1956). Writing and figuration are basically all one to abstract and synthesize reality and not to represent it. For this reason, figuration is linked to movement: the point moves, and a line derives from it as the first dimension; the line obtained, by moving, forms the two-dimensional plane. The collision of the planes results in a three-dimensional solid body. Klee, who is a musician, tries to set painting in analogy with harmonic systems, elaborating the elements of his themes like a specialist in the field, with notes, motifs, themes and modulations and despite supporting the need for a clear separation between the arts, evident are, especially in initial experiences, many points of contact with music. The very name of "Canon of Totality", attributed to his chromatic model, proves the close and complex relationship that the artist grasps between color and music, in a broader and more synaesthetic conception of "circularity and complementarity" of the various forms of art. Thus, we find works with a clear polyphonic or monophonic character, continuous melodies, based on uninterrupted lines, ascending and descending rhythms, tonal and atonal relations, etc. Numerous trips and exhibitions, including in the United States, preceded his appointment as professor at the State Academy of Düsseldorf in 1931. During this period, his production saw the succession of various stylistic tendencies: compositions with parallel lines that

thickened to the point of overlapping, references to compositional principles of a musical nature, with the use of gradations, planes on which colour stains were regularly distributed, large luminous fields crossed by parallel or converging lines. These abstract figures are sometimes superimposed on figurative fragments or human figures. From 1937 his style took on dark, dramatic tones, his poetic message was veined with suffering and pessimism; on a background (monochrome or polychrome) dense black brushstrokes appear and black are also the features that surround the colored areas. Klee is deeply anxious about the events in Nazi Germany, which also hurt him on a personal level. Klee's work, with its inimitable variety of expressions, occupies a central position in the artistic panorama of the twentieth century. It represents the affirmation of the creative freedom of an abstract language, in many respects similar to that of music and poetry. Klee's painting, sometimes reserved, soft, imbued with humour, often painful, visualizes the different spiritual and artistic tensions that characterize the existential dimension of the twentieth century.

#### **4. Developments, insights, denials**

As is well known, contradicting his previous obstinacy, from 1925 Kandinskij changed his mind, supporting Ostwald's theories, while Gropius and the designers, who until then had been more attentive and sensitive to technological aspects, also considered them benevolently.

Wilhelm's chromatic theory - in an unusual way compared to the custom of the contemporary Authors - placed green among the primary ones, together with red, yellow and blue. The colour wheel shown in his *Sillabario dei colori* (1916) assigns no less than nine of the twenty-four subdivisions to green; he did not discuss the concept of green as a "secondary" mixture of blue and yellow, but rather considered - and in a "mediated" position with respect to exclusively material and technical parameters - green as perceptively autonomous: a recognition of Goethe's psychological dimension of tributary colour. In turn, in fact, the chemist had derived his theories from the Viennese Gestalt psychologist Ewald Hering (Marotta 1999), who hypothesized three sets of "antagonistic colors", in great similarity with the Goethean oppositional categories.

However, among the salient aspects of Ostwald's chromatic thought, the role assigned to the grey component in colour emerges - with the proposal of the concept of "brilliance" - for the range of greys in coloured space. In his chromatic sphere, Otto Runge had tried to extend the Goethian Circle of Colours, lying on a plane, through a perpendicular axis, with the development (in the

space conceived in three dimensions) of tones, from the black pole to the white pole in the opposite pole, without considering the need to represent variations for the grey placed at the centre of the sphere.

The scientist was struck when, at Harvard in 1905, he had the opportunity to confront Albert Munsell, who had a three-dimensional idea of the chromatic system. The chemist wanted to translate this mental model into a series of easily recognizable principles that could guide the artists, allowing them to obtain a harmonic chromatic composition.

Thus, he developed a perceptual scale of gray tones that varied gradually and uniformly. These gradations were derived from a mathematical equation between the progressive percentages of black and white; Ostwald then applied the resulting range of greys to each of the shades of his twenty-four-part colour wheel, convinced that chromatic harmony arose from the application of colours whose values - with relative grey components - were compensated for. This was the central idea exposed in the *Sillabario dei colori*, which Klee irrevocably rejected. On the contrary, the artist recommends that painters "cut" the colors with white to harmonically balance the colors. The Nobel Prize winner, in a convinced and persistent way, continued the battle to defend his ideas. Thanks to his scientific expertise, he applied his theory effectively to the material aspects of the pigments from which he obtained the colours, and his role as consultant to the German paint industry enabled him to apply it to commercial products. In 1914 he organised an exhibition of industrial paints and dyes on behalf of the *Deutsche Werkbund*, the German association for art and design. In 1919 he opened a series of technical conferences on colour in Stuttgart, the tradition of which continues to this day.

If we wanted to give an example of the differences, in particular, between the concepts that differ most from Ostwald's convictions, in Paul Klee's thought there is the "dynamic" thought of the "peripheral chromatic movement" (Klee 1956): an infinite movement that takes place along the circumference and in contrast to the pendular movement that takes place along the diameter. Here the colors continuously pass into each other, there are no interruptions and every beginning is also the end. Each color starts from its nothingness, that is from the culmination of the near color, first slowly and then more and more growing until it touches its own culmination; it then begins to slowly decrease, toward its nothingness, that is toward the culmination of the other adjacent color. "If we consider, for example, the color red, we will not be wrong by fixing its width to two thirds of the circumference. There is a red that gives in yellow (the so-called warm red) and a red that gives nerazzurro (the so-called cold red).

But both of them represent, compared to pure red, a weakening. It must therefore be noted that red increases from one side or the other and this increase from two sides naturally leads to a climax, to a climax where red reaches its maximum height. Three points can then be established on the circumference: the red peak, the hot end of the red and the cold end of the red. These three points divide the circumference into a red line that measures two thirds, and a line without red that measures one third and is opposite to the red peak. In the same way the amplitude of yellow and blue can be determined" (Klee 1956).

Since the early decades of the twentieth century, Ostwald had strongly advocated his theories, obtaining greater consensus and support among the European artists of the time, both as a concrete basis for their work and as an object of criticism.

Among other things, he took on a charismatic role among the Dutch painters of *De Stijl*, such as Theo Van Doesburg, Jacobus Johannes, Oud and Piet Mondrian, although the latter, who was very attentive to the question of primary colours, struggled to understand what Ostwald's theory required in order to use colour correctly: should green be included or not?

## **5. Conclusions**

In addition to describing cultural matrices, parameters and essential characteristics of the models examined, of particular interest is the scope of the applications already put in place of the models, or possible future developments, also connected to new methodologies (such as virtual and digital) in the color project, up to the experiments in concrete and material production.

Following a methodological approach already developed and tested, the work will in the future tend towards a three-dimensional graphic interpretation and representation that - from a cultural and philological point of view - can be a tool for analysis and interrogation of sources. Specifically, quantitative elaborations should start from other assumptions to produce results of some interest. In this regard, it is useful to remember that it is always essential to make an explicit and reasoned declaration of the methodological approaches and parameters used, considered the most appropriate for the purposes of scientific investigations.

The visualization, also dynamic, of the single models, including the constituent parameters, constitutes a privileged laboratory for specialized scientific investigations, in which the dynamization will be able to render more effective the temporal sequences between the various models, also of different authors, in order to

highlight and confirm their developments through the parameters, as well as to better narrate the modifications in time, for example of similar models, between analogies and differences. This is especially true if we consider

them both in their original version and in their various reworkings, both in the related theories (with purely speculative aspects) and in their representations with more exquisitely formal and communicative characters (fig. 1).

Klee	Ostwald
Regulated freedom	Free rule
"Free"	"Scientific"
"Dynamic"	"Regulatory, regulatory, programmatic"
"Sensory, multisensory,"	"Visual, perceptual,"
"Gestaltic"	Harmony comes from the order of Science
"Synaesthetic"	"Energetist"
"Symbolic"	"Idealist"

Fig. 1. The "Reverse Oxymoron" represented in the table summarizes in the first instance the possible categories to evaluate convergences and differences between Klee and Ostwald.

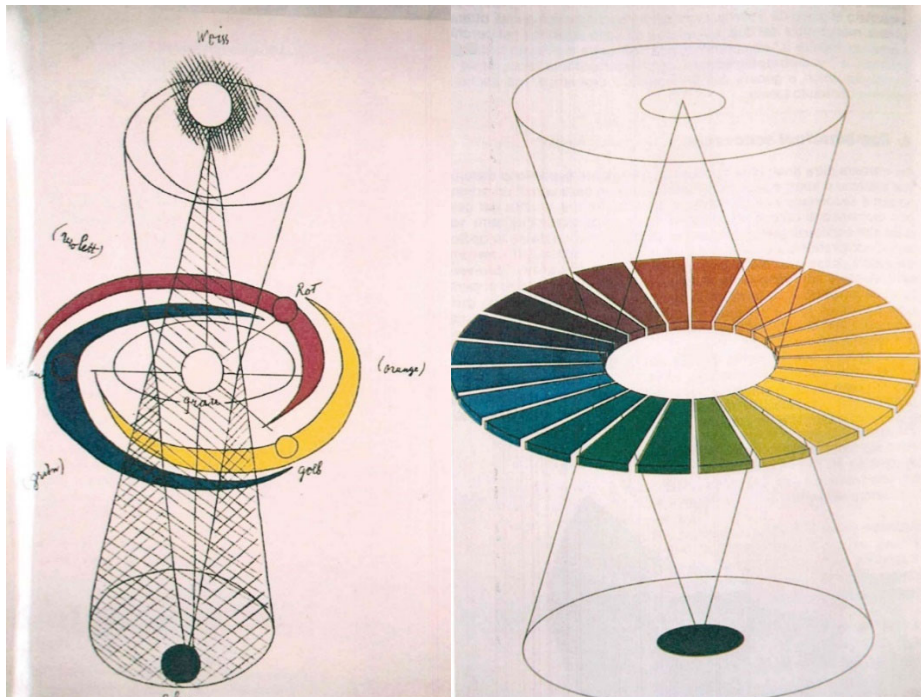


Fig. 2. Paul Klee, *The Canon of Totality*, 1922. Source: Anna Marotta, *Policroma* [...], p. 131.

Fig. 3. Wilhelm Ostwald, *Double cone*, 1915-1919. Source: Anna Marotta, *Polychrome* [...], p. 125.

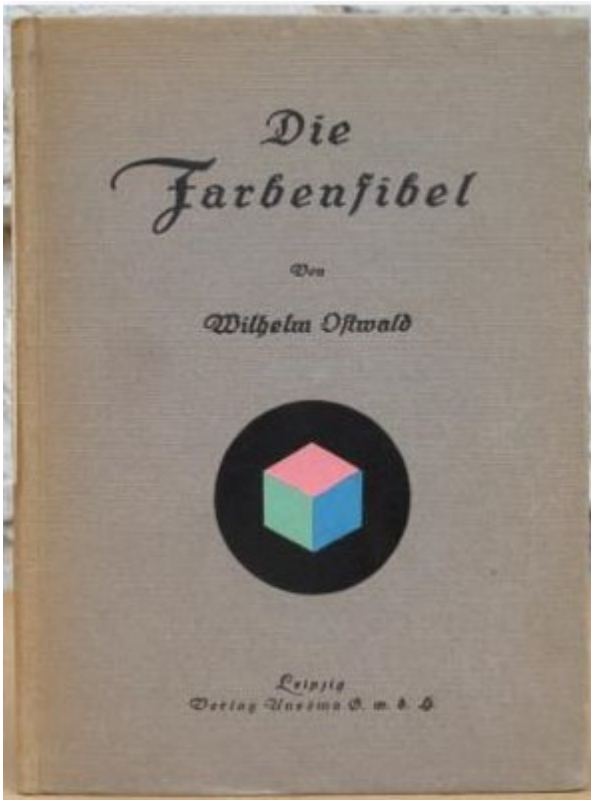


Fig. 4. Wilhelm Ostwald, *Die Farbenfibel*

Fig. 5. Wilhelm Ostwald, amateur artist and Nobel Prize winner for Chemistry.



Fig. 6. Paul Klee, *The fixing of pigments on the chromatic disc*, 1922. Source: Paul Klee. *Theory of Form and Figuration*, Milan, 1959, fig. 1, p. 509.



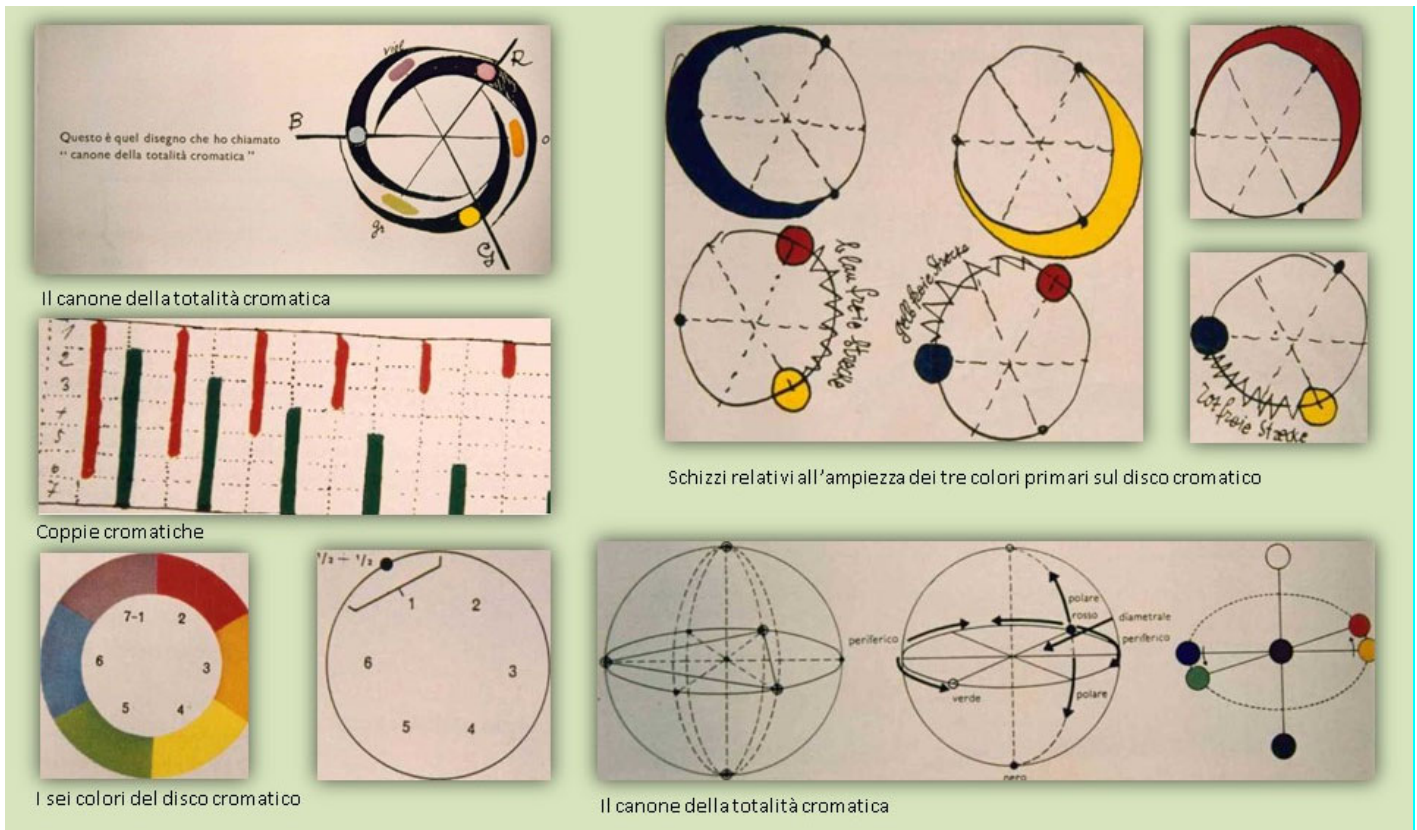


Fig. 7. Visualizations of possible chromatic comparisons, also in relation to brightness. In particular, for the chromatic pairs Klee paid attention to the "false" or "authentic" ones, such as the complementary colours red and green. Source: Paul Klee. *Theory of Form and Figuration*, Milan, 1959, fig. 1, p. 472.

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The author declares, that nothing has affected her objectivity or independence in the production of this work. There are no actual or potential conflicts of interest, including financial, personal or other relationships with other people or organizations.

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## References

- Marotta A. (1999) *'Policroma, Dalle teorie comparate al progetto del colore'*, Torino: Celid.
- Marotta A., Vitali M. (2017) *'La modellazione tridimensionale come espansione concettuale dei modelli del colore'*, Napoli: XIII Conferenza del Colore 2017.
- Geelhaar C. (1972) *'Paul Klee und das Bauhaus'*, Köln: DuMond Schauberg.
- Cherchi P. (1978) *'Paul Klee teorico'*, Bari: De Donato
- Klee P. (1920) *'Confessione creativa'*, Schöpferische Konfession, Norderstedt: BoD Buchshop.
- Klee P. (1956) *'Das Bildnerische denken. Schriften zur form und gestaltungslehre'*, Basel: Schwabe & Co. Ed. italiana: DORFLES G. (acura di), *Teorie della forma e della figurazione*, Feltrinelli, Milano 1959.
- Ostwald W. (1922) *'Die Farbenfibel'*, Verlag Unesma GmbH
- Birren F. (1969) *'The color primer: a basic treatise on the color system of Wilhelm Ostwald'* New York: Van Nostrand Reinhold.
- Wingler H. M. (1962) *'Das Bauhaus. Weimar-Dessau-Berlin 1919-1933'* Bramsche: Rasch & Co. Verlag. Ed. italiana: F. Dal Co (a cura di), *Il Bauhaus. Weimar-Dessau-Berlino. 1919-1933*, Feltrinelli, Milano 1972, p. 312.
- Zevi B. (1974) *'Poetica dell'architettura neoplasticista'* Torino: Einaudi.
- Itten J. (1962) *'Kunst der Farbe'* Ravensburg: Otto Maier.
- Albers J. (1962) *'Interaction of color'*, New Haven: Yale University Press.



# Under the lens of *ISLe*: Leonardo da Vinci's "Landscape" drawing analysed by colourimetry

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## ABSTRACT

On the occasion of the fifth centenary of his death, the Museo Leonardiano da Vinci celebrates its anniversary with the exhibition "Leonardo a Vinci. At the Origins of the Genius" which includes the exhibition of the drawing of *Landscape*, dated August 5, 1473, kept at the GDSU of the Uffizi Galleries in Florence. The University of Bologna has been asked to make a 3D rendering of the drawing that could be used as a substitute, capable of investigating, describing and communicating the drawing, its methods and contents, faithfully reproducing its form, characters and appearance. The answer was the *ISLe* application, a means of observing and understanding, interpreting and envisioning drawings and therefore able to penetrate the secrets of Leonardo's *Landscape*. Technically, *ISLe* aims to provide a unified answer to two distinct and complementary questions: the first is the creation of drawing archives that can accurately describe the information of the original analogical physical system; the second is related to the methods for the collection and rendering of 3D drawings, i.e. those systems and techniques that allow for the reproduction and systematically show a perception of the form three-dimensionally thus creating a visual evaluation of the current state of conservation of the drawing, of the superimposed sedimentation and of any restorations received over time. This paper describes the experience and results.

**KEYWORDS** Leonardo da Vinci, Antique drawings, Colour analysis, 3D, Visualisation, MTF, LED light.

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## 1. Introduction

On the occasion of the fifth centenary of his death, the Museo Leonardiano da Vinci celebrates its anniversary with the exhibition "Leonardo a Vinci. At the Origins of the Genius" which includes the exhibition of the drawing *Landscape*, dated August 5, 1473, kept at the GDSU of the Uffizi Galleries in Florence (inv. 8P). It is a small representation written on a sheet of 196x287 mm, i.e. about an A4, in pen and iron gall ink of four different shades, red stone and lead tip on paper, which presents the famous depiction of landscape on the front and a series of figures on the back. A complex system of signs that has never allowed a definitive answer to a series of questions that still remain open today.

What is inside that tiny drawing, smaller than an A4 format and 50 cm away already concealing secrets to the human eye? What did Leonardo think when he drew the *Landscape*? What does the *Landscape* represent? The Valdarno as some people want it to be? Or the Marmore Falls as others want? And how did Leonardo manage to draw his subjects so quickly and so effectively, still today incredible to the vision? Was it the work of Leonardo alone, or, as some scholars claim, is the sheet an extraordinary example of dialogue between Andrea del Verrocchio's collaborators and perhaps Verrocchio himself?

In order to try and answer these questions on the occasion of the exhibition, the University of Bologna has created a three-dimensional digital communication artefact called *ISLe*, which allows the drawing to be reproduced with perceptual fidelity to the shape, characters, colour and appearance on a 55" 4K touch table, interacting with it as if it were in the hands (Fig. 1). *ISLe*, born from a series of experiences conducted over a decade (Gaiani et al. 2011; Gaiani et al. 2012, Apollonio, et al., 2015), using five photographs, reconstructs the three-dimensionality of the drawing, rendering it digitally as a computer graphics image under all conditions of lighting and observation, with perceptual fidelity of high colour and a resolution of 50  $\mu\text{m}$ .



Fig. 1. Leonardo da Vinci's *Landscape* drawing seen through *ISLe*.

In order to faithfully reproduce the original *ISLe*, rather than use the traditional solutions based on 2D (i.e. very high resolution images) or 2D1/2 (e.g. Reflectance Transformation Imaging techniques (Malzbender et al., 2001)), it adopts a completely 3D paradigm, relying on the concept of 'total appearance' (Wilkie, et al., 2009). The developed solution aims to reconstruct the entire spatial reflectance of the artefacts in order to appreciate not only the graphic characters of the work (signs and traces), but also the undulations of the paper, as well as the critical conservation of the sheet due to corrosion of the acidity of the inks and other accidents, such as exposure to light and other atmospheric agents, which have affected the artefact over time. From an operational point of view, the solution consists in the evaluation of a Bidirectional Scattering Distribution Function (BSDF) and its rendering in real-time rendering (RTR), using a simple acquisition scheme and not harmful to the design.

The system follows in its entirety the one used in Leonardo's previous experience of *Vitruvian Man* (Gaiani, et al., 2015), introducing, however, countless innovations, starting from the same basic scheme, for the desire to improve some characters that already at the end of the previous experience had shown the possibility of improvements: the accurate reproduction of colour, the morphological configuration of the design, the reflection model of paper and ink.

From a technical point of view, *ISLe* is composed of six sub-systems:

a. An effective 48-bit colour capture, using an integrated camera-back scanning solution: the Rencay DiRECT Camera Systems 24k<sup>3</sup>. This camera features a Kodak KLI-8023 CCD sensor trilinear RGB with 8000 pixels per sensor, for a native resolution of 13000 x 8000 pixels and a maximum resolution of 39000 x 24000 pixels. The pixel pitch is 9  $\mu\text{m}$  which allows a resolution limit of 55 lp/mm with 60% contrast. The lens used is a Rodenstock Apo-Macro-Sironar-Digital 120mm. f/5.6 72x96 performing excellent resolution even at the corners, limited distortion and uniformity of illumination;

b. A lighting system based on individual High Flux LEDs with white light Relio2 (<https://www.relio.it/>), an illuminator emitting continuous spectrum light at a CCT of 4000°K, a neutral white with high colour rendering, a brightness of 40,000 lux at 0.25 m and a CRI > 95%. It avoids the typical problems of fluorescent illuminators that do not allow the acquisition of information at certain wavelengths of light (Fig. 2) in addition to the presence of harmful ultraviolet (UV) and infrared (IR) rays;

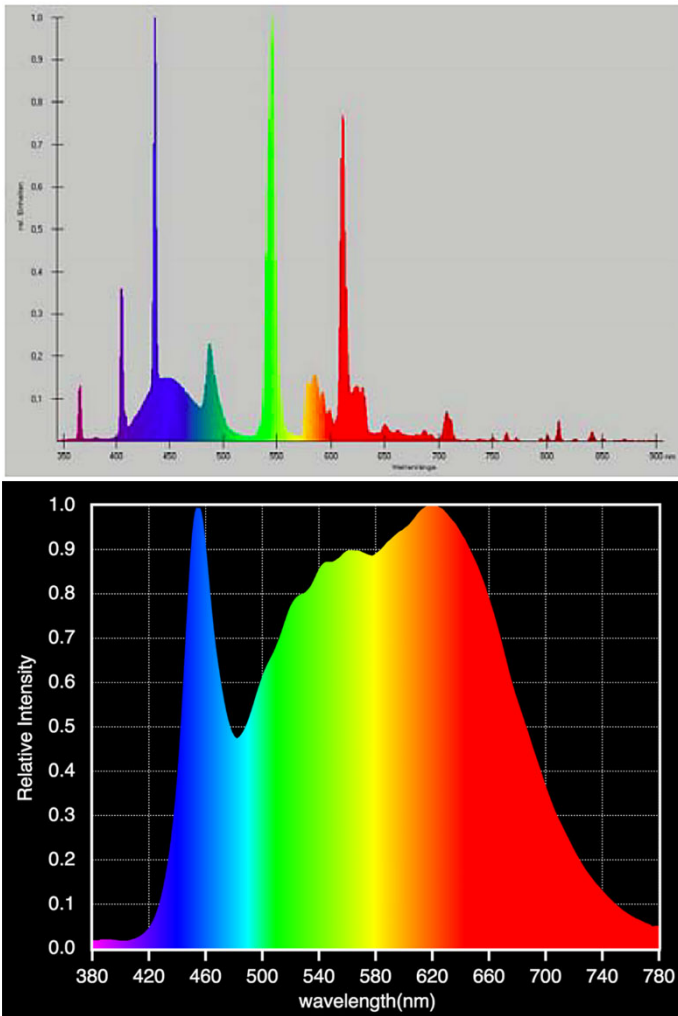


Fig. 2. Spectral Power Distribution of fluorescent light tubes for photographic use (left) compared to that of the Relio2 4000K lamp (right).

- c. A computational model to give micro and macroscopic fidelity to the surface within a rendering window based on the OpenGL graphics libraries;
- d. A software allowing an excellent Colour Correction from RAW images to faithfully reproduce the colour;
- e. A solution to visualize the high-fidelity communication artefact using a rendering engine low-cost and portable on multiple devices (wall, monitor, PC, tablet, smartphones);
- f. A visualization interface for visitors to museums and exhibitions based on touch and gestures usual because they are borrowed from those of smartphones.

Using *ISLe*, *Landscape* drawing has been examined as a graphic artefact through visual and colourimetric analysis. The paper shows the analysis results and a technical description of *ISLe* features more closely related to the type of analysis proposed.

## 2. Capture sharpness and resolution

The determination of the artist's tracing properties can be qualified only in the presence of an appropriate effective resolution of the images, in order to ensure the reproduction of all significant details present in the original document on the display device.

Two parameters must be measured to define the resolution: spatial detail and its preservation.

The necessary spatial detail can be established by a preliminary analysis of the document (MacDonald 2010). In this specific case, as already emerged from the analysis of other of his drawings, the trait of Leonardo's drawings is particularly challenging. The reference data reveal, in fact, sign values at a minimum of 90  $\mu\text{m}$  thickness, while the wire rods making up the paper have a size of about 700  $\mu\text{m}$ .

Following Shannon-Nyquist's sampling theorem, the resolution required to faithfully represent the structural characteristics of the *Landscape* is at minimum 565 ppi.

The measure of its conservation has been realized at different spatial frequencies through the measurement of the frequency transfer function (MTF - Modulation Transfer Function) (Jacobson, 1995), estimated by the spatial frequency response (SFR), i.e. the normalized module of the Fourier transform of a line diffusion function (LSF) (Ridler and Calvard 1978). The measurement of MTF is coded by the ISO 12233:2000-2017 (ISO 2017) standard, which provides for three metrological protocols, the most common of which is the one providing for the measurement of the slanted edge (Burns 2000). The method, which produces the Edge Spread Function (ESF) by scanning the image of an edge, has several advantages:

- The distance between camera and lens does not fit into the equation that converts the image to MTF response (it is invariant at scale);
- Inclined edges take up less space and are less sensitive to noise than sinusoidal models;
- MTF can be measured at Nyquist frequency (0.5 cycles / pixel) thanks to the binning/oversampling algorithm.

The characterization of the effective resolution was then carried out by measuring the MTF using an ISO 12233:2000 target size 200 x 356 mm and the software Imatest Studio version 4.5. The choice of the target defined in the 2000 standard has been made both because its defects do not particularly affect the results in the case in question, and because of the possibility of comparing the current results with those obtained in previous

experiences with the same shooting system and similar subjects.

Base acquisition values		
	Venice	Florence
MTF50	0,099 Cy/Px	0,1425 Cy/Px
LW/PH	1600	2280
MTF10	0,26 Cy/Px	0,415 Cy/Pxl
MTF at Nyquist	0,00602	0,0545
10-90% rise	5,37 Px =1490 per PH	4,34 px =1845 per PH
Effective resolution	335 Px/inch	483 Px/inch

Acquisition values adding Unsharp Mask filter		
Venice [Intensity: 200; Radius: 1; Threshold: 6,00; Edge Offset: 0,00]		
Florence [Intensity: 150; Radius: 1; Threshold: 4,00; Edge Offset: 0,00]		
	Venice	Florence
MTF50	0,1699 Cy/Px	0,1791 cy/Px
LW/PH	2718	2865
MTF10	0,373 Cy/Px	0,452 Cy/Px
MTF at Nyquist	0,137	0,067
10-90% rise	4,99 Px =1604 per PH	4,76 Px =1682 per PH
Effective resolution	575 Px/inch	683 Px/inch

Tab. 1 - Vertical MTF. Comparison of MTF values in the two acquisitions: *Vitruvian Man*, 2014; *Landscape*, Uffizi, 2018.

The reference parameters were essentially two: MTF10 and MTF50. The MTF10, i.e. the frequency associated with the MTF response point of 10%, is used to evaluate the resolution capacity, i.e. the maximum resolution. The MTF50 is the most suitable parameter of image sharpness and to compare the sharpness of cameras and lenses.

In addition, the MTF technique has been used to evaluate the appropriate sharpening of image to remove the lens and sensor blur not achieved in-camera using an image editor and Unsharp Mask filter (UM). UM filter principle of operation is based on the fact that the contours of objects are locally areas of high contrast. In particular, an iterative system for finding the parameters of the UM was developed to minimize the phenomena of oversharpening

and undersharpening, as proposed in (Williams and Burns, 2008). Ultimately, the response with respect to a slanted edge in terms of rising distance (rise 10-90%) and the MTF curve as function of the spatial frequency expressed in units of cycles per pixel, measured by the values of MTF50 and MTF10, were calculated. The average spatial resolution (horizontal and vertical) on an acquired image size of 13000 x 8000 pixels corresponding to a sampled area of 205.1 x 333.35 mm corrected with UM (values: Intensity: 150; Radius: 1.00; Threshold: 4.00; Edge Offset: 0.00), was for the rise 10-90% = 4.00 pixels; in the frequency domain was obtained an average MTF50 = 0.2445 Cycles/Pixels and an average MTF10 = 0.336 Cycles/Pixels, corresponding to an effective resolution of 740 px/inch (Tab. 1) capable of resolving details of 60 µm, finer than the minimum required.

Finally, the MTF values were compared with those recorded in 2014 on the occasion of the acquisition of the *Vitruvian Man* (Apollonio et al., 2015). The data resulting from the two experiences, despite the inevitable operational differences regarding some components of the equipment (such as the optical group of the target), confirmed the reliability of the procedure, and showed a slight improvement in the performance of the entire acquisition system in terms of quality of resolution, with an increase in the value of MTF50 and MTF10 and consequently of that of the actual resolution.

### 3. Colour Correction

A fundamental problem in the digital acquisition and reproduction of fine art drawings is the chromatic and tonal definition of the graphic work which, in our solution, must be framed within the more general topic of the complete definition of the material's properties, i.e. the Bidirectional Scattering Distribution Function (BSDF), so that it can be identified in the acquisition and reproduction of a colour map and a rendering algorithm.

Since the digital rendering of the reflection of a surface requires strong simplifications of the physical behaviour of light and its interactions with the surface in order to be calculable in a reasonable time, in the development of *ISLe* we have set ourselves the acceptable objective of restoring at least perceptual fidelity to the colour. For this reason, we followed a colourimetric approach based on the colour correction (CC) of the acquired RAW images, following a target-based technique, a particularly efficient solution when it is possible to define the requirements of the images and carry out the image under similar conditions of the target and of the subjects to be represented, exactly our case.



A fully automated CC solution developed by our team, so-called SHAFT (SAT & HUE Adaptive Fine Tuning) (Gaiani and Ballabeni 2018), was adopted for ISLe. It is based on an X-Rite ColorChecker Classic target (McCamy et al., 1976) (the expected values of which were obtained by measuring the patches of the ColorChecker used using a Minolta CM-2600 D ball spectrophotometer) and a two-stage CC process. A first correction is made using a per-channel polynomial fitting algorithm based on the MATLAB *Weighted Polyfit* ( $x,y,n$ ) function. The algorithm is explained in detail in (Gaiani, et al. 2017). A second correction is made using the actual SHAFT procedure *Weighted Polyfit* ( $x,y,n$ ).

The process adopted follows the usual five rules of colourimetric imaging:

1. Correlated colour temperature (CCT) of the illumination 5000°K (D50 workflow);
2. Optimal exposure;
3. Colour profile based on  $\Delta E$  minimisation with excellent brightness accuracy;
4. Target-independent validation used to create the camera profile;
5. Coding space capable of not cutting object colours.

As final encoding colour space we selected the sRGB-IEC 61966-2-1 whose values are defined with respect to CIE illuminant D65. Its potential contraindications (non-linearity, size smaller of the colour space perceived by humans) do not influence the colour quality of ISLe rendering. The *Landscape* not present badly representable colours by the sRGB colour space. In fact, iron gall ink, black chalk, red chalk and paper have colours completely inscribed in the sRGB colour space, without the need for colour clipping or remapping. On the other hand, the use of sRGB has a number of advantages including, mainly, full support from the 3D Graphic API used (OpenGL) and 100% displayability on today's monitors.

The CC workflow is instead completely realised in the linear space CIEXYZ. The reason is in the observation that, using this colour space, the errors calculated by the least squares fitting algorithms correspond very well to the deviations of the images corrected to the original, so fewer numerical deviations correspond to more visually accurate images (Lukac and Plataniotis 2007).

For the evaluation of the error in the correction both during the CC process and in the final validation, the colour metric issued by the CIE in 2000 (Sharma et al. 2005), calculated for each colour patch, was used.

As suggested e.g. in (Williams and Burns, 2016), a metric dispersion analysis was used in addition to the evaluation of the average  $\Delta E_{00}$ .

The results show an average value of  $\Delta E_{00} = 2.21$ , an average brightness accuracy of  $\Delta L_{00} = 0.59$  and an exposure error of 0.02 f-stop (Fig. 3).

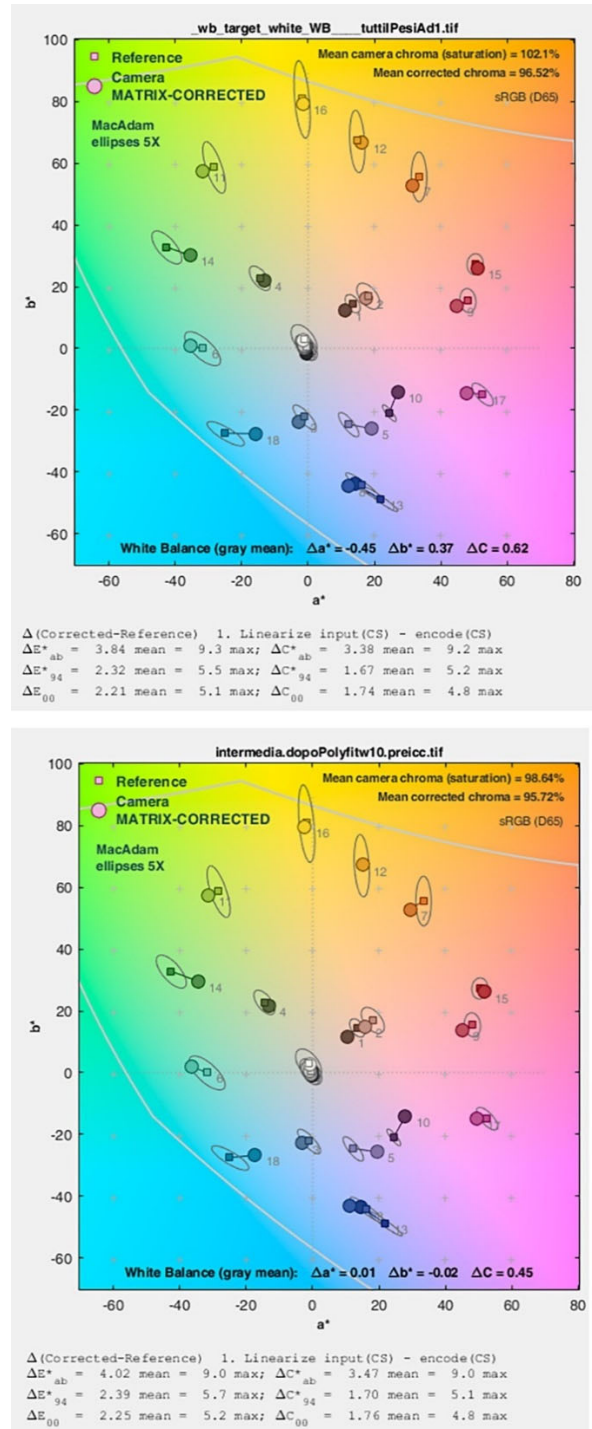


Fig. 3. Evaluation of the results of the CC using equal weights of all patches (above) and different weights between the various patches (below)

However, the evaluation of the  $\Delta E_{00}$  error on the individual patches led to significant problems in the area of the yellow



(for the D3 patch we reported a  $\Delta E_{00\text{mean}} = 4.2$ ) and partially of the red (for the C3 patch we reported a  $\Delta E_{00\text{mean}} = 2.8$ ), confirmed by direct and comparative observation of the correct images and the original drawing. This restates the observation of many authors that the CC procedure using standard colour targets is problematic when the object to be reproduced is characterized by a limited range of colours close to neutral colours, which is the typical case of the drawings (Berns et al. 2005, Trumpy 2010).

The experimentation of some solutions proposed in the literature, such as the construction of a personalized chromatic target with patches empirically chosen within the palette of colours present in the original (Williams and Burns, 2012), has shown a strong aleatory in the choice of candidate colours, as well as the verification using a different target from the original one has led to unsatisfactory results for the difficulty to reproduce measured distributions of colour not too dissimilar (Williams and Burns, 2016b).

A different procedure was therefore preferred:

A. From the images of the drawing (recto and verso) obtained from the standard CC process, corrected images were created manually using Adobe Photoshop on two different calibrated monitors (NEC Spectra View 2690 and Spectra View Reference 302) respectively at 5000°K and in sRGB colours for visual comparison with the original drawing placed next to the monitors and illuminated with the LED lamp used for the acquisitions until obtaining perceptively marginal differences at the prolonged observation of five expert users;

B. on a RAW image the CC process was carried out with SHAFT but giving different weights to the patches of the ColorChecker Classic emphasizing the neutral A4-F4 and those of the colours closest to those present in the drawing. This procedure has been repeated for various weights;

C. the images of the drawing thus obtained were compared by 20 expert subjects with respect to the original drawing illuminated with the LED lamp used for the acquisitions on the two NEC Spectra View monitors calibrated as above (5 people) and with respect to the correct image manually (20 people of which 5 on the two NEC Spectra View monitors, 15 people on the LaCie 526 monitor calibrated with respect to the sRGB colour space).

Considering that the changes in ambient light only affect the perception of absolute colour, but have no effect on the relative sensation of colour difference (Hao et al. 2011), the verification was held in two differently lit environments capable of allowing an observation as close as possible to that defined by the standard ISO 3664:2009 (ISO 2009).

All observers found perceptually marginal differences in the prolonged observation of the images in which was assigned a weight 2 to the patches A1, B1, A2, F2, C3, D3 and A4, and a weight 3 to the patch F4.

For this CC solution we achieved a  $\Delta E_{00\text{mean}} = 2.25$ , a  $\Delta L_{00\text{mean}} = 0.63$  and an exposure error of 0.00 f-stop which corresponds to the indistinguishability from the real on a calibrated monitor. Moreover, for the D3 patch we obtained a  $\Delta E_{00\text{mean}} = 2.88$  and for the C3 patch a  $\Delta E_{00\text{mean}} = 2.27$  (Fig. 3).

#### 4. The Landscape seen through ISLe

Here we briefly summarise only some of the main characters of the drawing compared with those of another drawing by Leonardo: the famous *Study of proportions of the human body*, previously acquired and analysed (Apollonio, et al., 2015). As main literary reference were used for the first drawing the Alessandro Nova's essay "*Adj 5 daghossto 1473*" (Nova 2015) and for the second one a paper by Loretta Salvador, the last restorer of the drawing (Salvador 2009).

The *Landscape* drawing has laid wires placed at regular intervals, horizontally, of a size of about 800  $\mu\text{m}$  (13 lines per 10 mm approx.). These laid wires are well distinguishable on the front and are almost indistinguishable on the back, demonstrating that this was the part of the paper most treated, contrary to what happens in *Vitruvian Man* who shows the laid wires on the back, while they are not perceptible on the front. Chromatically, the paper is very similar to that of the drawing in Venice today, because it took three areas of 250 x 150 pixels in more parts of the drawing (front of both) blurred using a bilateral filter (Paris et al. 2009) and normalized the brightness, the average values read were for the *Landscape*  $L^*a^*b^* = 87\ 4\ 11$ , for the *Vitruvian Man*  $L^*a^*b^* = 87\ 4\ 13$ . The two drawings, on the other hand, have different average luminosity, for the *Landscape*  $L^* = 82$ , for the *Vitruvian Man*  $L^* = 87$ .

This last circumstance may be due to different causes, which may range from exposure to sunlight to the treatment of paper.

The comparison between the back of the 8P and the front of the *Vitruvian Man* shows identical colourimetric values. Taken three areas, as in the above analysis, the average values are  $L^*a^*b^* = 87\ 4\ 15$ , supporting the hypothesis that the main face of the *Landscape* is the one that is currently commonly identified as verso.

	Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Point 7	Point 8	Point 9
<b>L</b>	55	54	54	47	45	44	41	42	47
<b>a</b>	12	12	16	12	12	13	13	11	10
<b>b</b>	26	24	26	16	14	14	16	13	14

Tab. 2 - Leonardo da Vinci, Landscape, colourimetric analysis of inks from images acquired, recto.

	Point 1	Point 2	Point 3	Point 4	Point 5
<b>L</b>	36	36	37	44	44
<b>a</b>	5	9	7	12	10
<b>b</b>	8	10	12	17	15

Tab. 3 - Leonardo da Vinci, Landscape, colourimetric analysis of the inks from the images acquired, towards

The colourimetric analysis of the inks identifies the use of two distinct substances that constitute two distinct graphic layers of the drawing. The first one includes the general layout of the composition, with what has been interpreted as the Fucecchio marshes, the hill on the right, the mountains in the background, the trees, and the layout of the hill on the left. The second instead includes the spur above the squared rocks, the waterfall, a series of retouches in the lower part, the confluence between the two rivers, and what has been recognized by some authors as the castle of Montevettolini. Table 2 shows the values in the L\*a\*b\* scale for the samples extracted, located in the same table and Fig. 4 shows details extracted from the application that well show the realization with two different inks/instruments. Fig. 5 divides the traits of the drawing into two large families identified using the K-Means Clustering segmentation algorithm based on colour (Arthur and Vassilvitskii 2007).

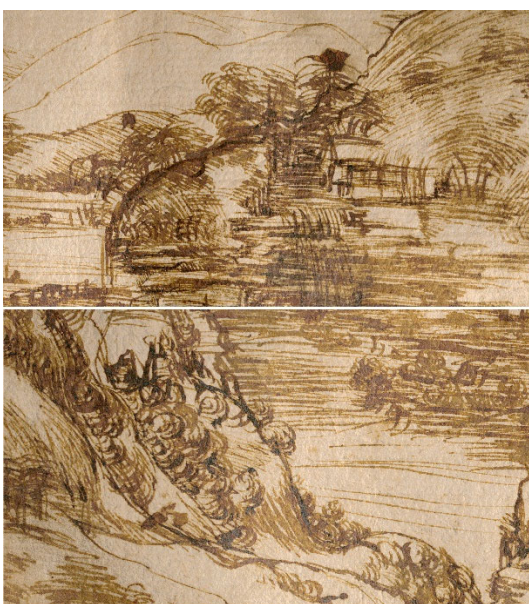


Fig. 4. Leonardo da Vinci, the Landscape seen through ISLe: different inks/instruments on the front of the drawing.

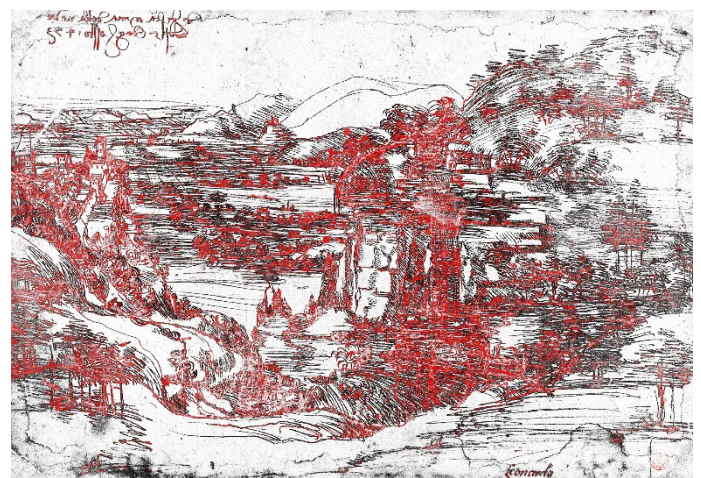


Fig. 5. Leonardo da Vinci, the Landscape seen through ISLe: different inks/instruments on the front of the drawing.

According to the colourimetric analysis, also the back of the drawing is made with two different inks. Their today colour is even different from those present on the front. An ink is used to draw the naked man in movement, the head in profile on his left and the words "Jo Morando dant[oni]o sono chontento". The second ink is used to sketch the mountainous landscape with the bridge over a stream and the foliage of the trees. Table 3 shows the values on the L\*a\*b\* scale for the samples extracted.

Compared to *Vitruvian Man*, in whom two different ink are used to write and to draw the variation of chromaticity of the inks in the Landscape is much wider. This variation can be appreciated also by non-expert observers while the chromatic differences of inks used in the drawing today in Venice are much less evident and perceivable only by an expert observer.

As for the stroke, on the front of the 8P we can see the use of two different types of pens, one used for the background layer with a stroke width of 0.7-1.5 mm (and usually 1.2 mm), and one for the foreground layer with a width of 1.2-2 mm (and usually 1.7 mm).

It is a very different technique from the one used in the *Vitruvian Man* where the freehand strokes have an almost constant width of 0.3 mm and the straight strokes drawn on the groove have an almost constant width of 0.2 mm, as that drawing is without smudges, "perfect for a technical drawing that had to "prove" the proportions" (Salvador 2009).

## 5. Conclusion

The observation of the *Landscape* drawing through the colourimetric and the stroke analysis allowed to focus on features otherwise difficult to observe. It emerges, completely in line with the Alessandro Nova statement, that this drawing is a complex graphic system, certainly produced in several phases, a sort of work-in-progress that has generated various figurations, of which what appears today on the front is the most striking result for the character of completeness despite it is the result of at least two different tools each of which is used in a specific and homogeneous area of the drawing.

## 6. Conflict of interest declaration

The authors declare no conflict of interest.

## 7. Acknowledgment

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## References

- Apollonio, F. I., Clini, P., Gaiani, M., Perissa Torrini, A. (2015) 'La terza dimensione dell'Uomo vitruviano di Leonardo', *Disegnare Idee Immagini*, 50, pp. 48-59.
- Arthur, D. and Vassilvitskii S. (2007) 'k-means++: The Advantages of Careful Seeding', in *Proceedings of the Eighteenth Annual ACM-SIAM Symposium on Discrete Algorithms*, pp. 1027-1035.
- Berns, R. S., Taplin, L. A., Nezamabadi, M., Zhao, Y., and Okumura, Y. (2005) 'High-Accuracy Digital Imaging of Cultural Heritage without Visual Editing', in *Proceedings of IS&T Archiving Conference*, pp. 91-95.
- Burns P.D. (2000) 'Slanted Edge MTF for Digital Camera and Scanner Analysis', in *Proceedings of IS&T PICS Conference*, pp. 135-138.
- Gaiani, M., Corsi, C., Faietti, M., Rossi, I., and Zancolich, M. (2011) 'An unified, fast and low cost workflow for fine art drawing collections acquisition', in Rossi M. (ed.), *Colour and Colorimetry Multidisciplinary Contributions*, VIIB, pp. 45-52.
- Gaiani, M. Ricci, P. C., and Zancolich, M. (2012) 'Una metodologia low-cost per l'analisi tramite metodi 3D di disegni antichi mantenendo la consistenza del colore', in Rossi M., Siniscalco, A., (eds.), *Colore e Colorimetria - Contributi Multidisciplinari*, VIIIA, pp. 15-22.
- Gaiani, M., Apollonio, F. I. and Clini, P. (2015) 'Innovative approach to the digital documentation and rendering of the total appearance of fine drawings and its validation on Leonardo's Vitruvian Man', *Journal of Cultural Heritage*, 16 (6), pp. 805-812. doi: 10.1016/j.culher.2015.04.003.
- Gaiani, M., Apollonio, F. I., Ballabeni, A. and Remondino, F. (2017) 'Securing Color Fidelity in 3D Architectural Heritage Scenarios', *Sensors*, 17 (11), pp. 2437-1 2437-24. doi: 10.3390/s17112437.
- Gaiani, M. and Ballabeni, A. (2018) 'SHAFT (SAT & HUE Adaptive Fine Tuning), a new automated solution for target-based color correction', in Marchiafava, V. and Luzzatto L. (eds.), *Colour and Colorimetry Multidisciplinary Contributions*, XIVB, pp. 69-80.
- Hao, Y., Liu, H., Chen, Y., Jiao, A., and Zheng N. (2011) 'Research on Digital Image's Color-Difference Threshold under Different Lighting Levels', in *Proceedings of 4th International Congress on Image and Signal Processing*, pp. 1723-1727.
- ISO (2017) 12233:2017 Photography - Electronic still picture imaging - Resolution and spatial frequency responses.
- ISO (2009) 3664:2009 Graphic technology and photography - Viewing conditions.
- Jacobson R. E. (1995) 'An Evaluation of Image Quality Metrics', *The Journal of Photographic Science*, 43, pp. 7-16. doi: 10.1080/00223638.1995.11738604.
- Lukac, R. and Plataniotis, K.N. (2007) 'Single-Sensor Camera Image Processing', in Lukac, R. and Plataniotis, K.N. (eds.) *Color Image Processing - Methods and Applications*, CRC Press, pp. 363-392.
- MacDonald L. (2010), 'The limits of resolution', in *Proceedings of BCS EVA Conference*, pp.149-156.
- Malzbender, T., Gelb, D., and Wolters, H. (2001) 'Polynomial texture maps', in *ACM SIGGRAPH '01 Proceedings*. ACM press, pp. 519-528.
- McCamy, C.S., Marcus, H. and Davidson J. G. (1976) 'A Color Rendition Chart', *Journal of Applied Photographic Engineering*, 11 (3), pp. 95-99.

Nova, A. (2015). '«Adj 5 daghossto 1473»: l'oggetto e le sue interpretazioni', in Frosini, F. and Nova A. (eds), *Leonardo da Vinci on Nature. Knowledge and Representation*. Venezia: Marsilio, pp. 285-301.

Paris, S., Kornprobst, P., Tumblin, J. and Durand, F. (2009) 'Bilateral Filtering: Theory and Applications', *Foundations and Trends in Computer Graphics and Vision*, 4 (1), pp. 1-73. doi: 10.1561/06000000020.

Ridler, T. W. and Calvard, S. (1978) 'Picture thresholding using an iterative selection method', *IEEE Transactions on Systems, Man, and Cybernetics*, 8(8), pp. 630-632. doi: 10.1109/TSMC.1978.4310039.

Salvador L. (2009) 'Tecniche, stato conservativo e intervento di restauro', in Perissa Torrini A. (ed.), *Leonardo L'uomo vitruviano fra arte e scienza*. Venezia: Marsilio, pp. 57-67.

Sharma, G., Wu, W., and Dalal, E. N. (2005) 'The CIEDE2000 Color-Difference Formula: Implementation Notes, Supplementary Test Data, and Mathematical Observation', *Color Research and Application*, 30 (1), pp. 21-30. doi: 10.1002/col.20070.

Trumpy, G. (2010) 'Digital Reproduction of Small Gamut Objects: A Profiling Procedure based on Custom Color Targets', in *Proceedings of Conference on Colour in Graphics, Imaging, and Vision*, 1, pp. 143-147.

Wilkie, A., Weidlich, A., Magnor, M., and Chalmers, A., (2009). 'Predictive Rendering', in *ACM SIGGRAPH ASIA 2009 Courses*, Article 12, 428 p.

Williams, D. and Burns, P.D. (2008) 'Measuring and Managing Digital Image Sharpening', in *Proceedings of IS&T Archiving 2008 Conference*, pp. 89-93.

Williams, D. and Burns, P. D. (2012) 'Targeting for Important Color Content: Near Neutrals and Pastels', in *Proceedings of IS&T Archiving 2012 Conference*, pp. 190-194.

Williams, D. and Burns, P. D. (2016a) 'Rethinking Image Color Correction, Validation and Testing,' in *Proceedings of IS&T Archiving 2006 Conference*, pp.175-180.

Williams, D. and Burns, P. D. (2016b) 'Color Correction Meets Blind Validation for Image Capture: Are We Teaching to the Test?', in *Proceedings of IS&T International Symposium on Electronic Imaging*, pp. 218.1-218.4.

# A case study on light and colour for monuments and cultural assets

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## ABSTRACT

The enhancement of monumental assets through lighting requires particular attention. The absence of specific laws (except those for the prevention of light pollution and the perishability of certain assets) results in installations whose sole purpose is to make them visible, without offering an effective valorisation at night. In this contribution, it'll be presented a concept experience for the monumental complex of Neptune in Bologna (Italy), where the choices made were aimed at satisfying specific requests of the client, which also included the use of different shades of white and coloured light.

**KEYWORDS** Cultural assets, Lighting, Colour, Concept

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## 1. Introduction

The lighting of cultural heritage is an activity of primary importance, especially in a country like Italy, one of the states with the highest concentration of world cultural heritage (UNESCO 2019). It is normal that, despite a not always appropriate conservation policy, the intention of the structures in charge (but also of the population, which every day enjoys these assets) is that of maximising the value of the heritage. The most effective method of making the works of our history usable is undoubtedly that of extending their usability even in the evening and at night with an illumination capable of maximising their value. Despite the relatively low costs of implementing lighting systems, cultural assets are made to last, and electrical consumption is a very significant expense item for municipalities. Due to the price of functioning and upkeep, often installations are kept switched off, or without proper maintenance. Fortunately, technology has been of fundamental help over time. Not only to simplify lighting design, but also to drastically reduce consumption, without having to sacrifice the final result. The light sources and the respective control systems guarantee a high flexibility, which however raises some doubts, especially when they're used on elements of historical-cultural interest. In this paper, I will present a case study focused on the monumental complex located in Piazza del Nettuno in Bologna, which, in occasion of the ongoing renovation of the site, had to be enhanced by paying attention not to distort its nature.

## 2. The monument and its context

The monumental complex protagonist of the case study is the Neptune fountain located in Bologna (Italy). Built between 1563 and 1567, it is a brilliant example of cooperation by a team of artisans, artists, architects and engineers (Tuttle 2015). The monumental complex is located at the confluence of two important squares in old Bologna and is surrounded by impressive historic facades. A squarish basin composes it with a pedestal and a statue that crowns the whole; marbles of two colours and elaborate figures and bronze finishes immediately give the idea of the importance and the magnificence that wanted to be transmitted by this work. Pope Pio IV (Giovanni Angelo 'De Medici) commissioned the fountain, and the work had the complete supervision of Pier Donato Cesi, a Roman governor who summoned the architect Tommaso Laureti (called "*il Siciliano*") and the Flemish sculptor Jean de Boulogne (known as "*Giambologna*"). Also, the gathering of an impressive international workgroup and a considerable amount of money made it clear right from the start that the aim was to create what was destined to be considered the most beautiful fountain in Italy.

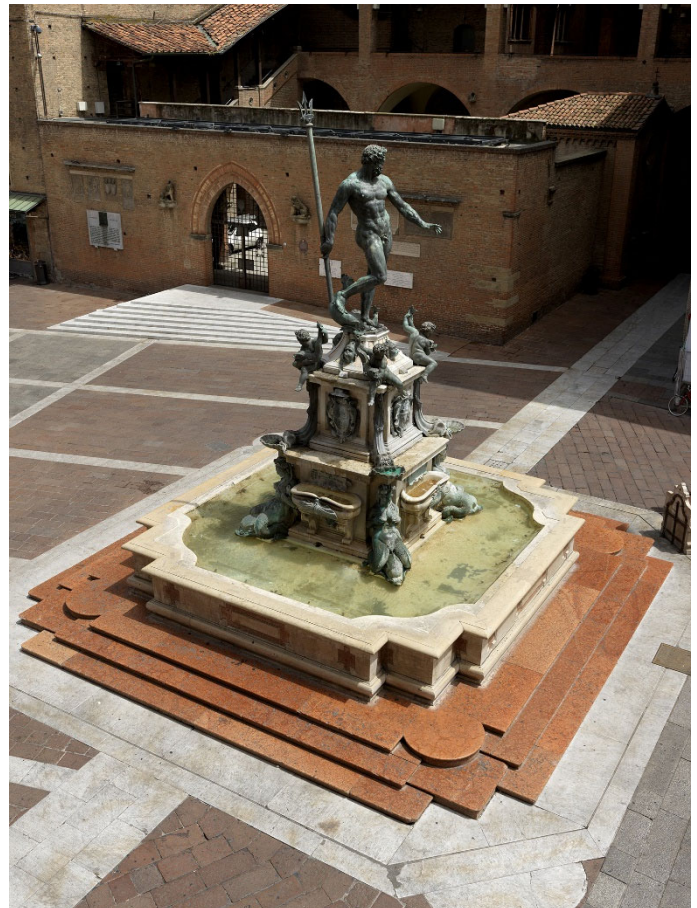


Fig. 1. The Neptune monumental complex seen from Palazzo d'Accursio. Courtesy of VISTAvisuals.

Although not as popular as other cities of art, Bologna registers more than 1.5 million tourists per year (Municipality of Bologna 2019) and pedestrian transit in this square is considerable even in the evening hours. Visitors walk on two main routes around the complex; the path to the right and the one to the left of the fountain. Via Rizzoli (to the north) and piazza Maggiore (to the south) are connected by these pathways. The imposing buildings of Palazzo D'Accursio and Palazzo di Re Enzo frame the fountain; both are large brick facades enriched by many characterising elements. On the ground, we find pink granite, darker granite slabs and the presence of elements in white marble (Figure 1).

Concerning lighting, currently the only attention given to the monumental complex is provided by a single roto-symmetrical projector for metal halide lamp with opening (estimated by the relative position between the fixture and the statue) that concentrates the entire luminous flux (light emitted by the source) in a cone of 6°. The particularity of this single projector is given not only by the lateral lighting of the statue (which guarantees a proper modelling of the forms) but also by the presence of a sharp shadow (probably will of the designer), the shape of the statue,

projected on the building that houses the offices of the municipality of Bologna.

The remaining lighting on the monumental complex is given entirely by the light that indirectly comes from the reflection of the historical facades and the pavement. As a result, the elements of the fountain are illuminated flatly and uniformly, and the differences between light and dark are exclusively due to the reflection factor of the material and the layer of oxide or deposits that covers most of the elements of the fountain.

### **2.1. The requests**

The client requested the Laboratorio LUCE of the Politecnico di Milano to produce three lighting concepts relating to the monumental complex and the surrounding spaces.

In formulating these concepts, a series of requests expressed by the client were taken into consideration, summarized in the following points:

- Minimise the consumption of electricity;
- Controlling diffused light;
- Contain the phenomena of discomfort glare towards passers-by;
- Enhance the monument of Neptune;
- Provide a clear legibility of the Fountain-Statue complex for the context, the surrounding buildings in the square, and its components;
- Use dynamic lighting solutions on special occasions, such as commemorations and anniversaries decided by the Municipality of Bologna;
- Lighting the Statue differently from the pedestal.

Initially, three concepts were formulated which, after several discussions with the client (who in turn interfaced with the municipality), were merged into a single preliminary proposal. The produced concept is not only intended to meet regulatory requirements, but also to interpret and enhance the space by mediating with communicative and functional requirements.

### **2.2. The preliminary analysis**

Before starting to gather ideas on how to enhance the complex with light, the Laboratorio LUCE staff provided a complete lighting survey on the fountain and its surroundings.

The survey aimed to evaluate the current state of the lighting system; instrumental measurements, photographic sessions and visual inspections were carried out to characterise the luminous scenario of the statue and the immediate surrounding areas. The reference standards for the measurements were UNI 11248:2012

(now replaced by UNI 11248:2016) and the European harmonised standard EN 13201\_02:2004.

The measured quantities taken into consideration are illuminance (amount of luminous flux per unit area) and luminance; photometric quantity correlated to the psychophysical sensation of luminance whose value depends on the position of the observer related to the surface itself (Fotios, & Gibbons 2018).

In addition to the lighting survey, a census was also made of the installed lighting fixtures and light sources (which will remain in good part even after a possible renewal intervention) in order to verify the functioning status of the systems but above all, the "quality" of the light present in terms of tonality and ability to reproduce colors.

After having carried out a census, it was possible to note that the light sources used are exclusively discharge lamps in traditional gases, of the two types (Rea, Bullough, & Akashi, 2009):

- High-Pressure Sodium Lamp - HPS
- Metal Halide Lamp - MH

The first type of lamp (HPS) is very efficient and is often used in urban lighting, where high colour rendering capacity is not required; in fact, this lamp emits a yellow-orange light, which offers a limited ability to distinguish colours, but allows the emanation of a considerable luminous flux with a modest electrical power consumption and consequently with reduced energy consumption.

Sodium lamps are mainly used to light the façades of buildings, i.e. in those parts of the space where yellow-green colours abound (part of the spectrum where this lamp is well-performing). In this way it is possible to obtain good results even if the Colour Rendering Index of the source is rather low. The colour rendering index (Ra) is a number between 0 and 100, used to express how much a light source can render the colours of a predefined set of colour samples (Guo & Houser 2004); that of the HPS lamp is about 20÷23.

The metal halide lamp, on the other hand, has a much higher colour rendering (Ra=65) but a lower efficiency than the HPS. Another factor is the colour temperature of the two sources, i.e. a parameter used to describe whether a white light source tends more towards a warm white shade (2000 K, typical of incandescent light sources) or a cool white shade (6500 K, characteristic of natural light with a clear sky). The MH lamps present are at a neutral colour temperature (about 4000 K).

These two combined characteristics are plausibly the reason why the MHs were chosen to illuminate the statue and some of the marble elements.

### 3. Coloured light for cultural heritage

The purpose of the proposal is certainly not to completely replace the luminaires of the area, of all the buildings and the monumental complex. The goal was to enhance the Neptune and its pedestal (the Castellum), and therefore, the current lighting on the areas not under consideration and will not be modified; however, following the lighting survey, we highlighted all the issues of the site.

Current technologies related to lighting sources allow us much greater flexibility, without compromising the efficiency of the sources. The LEDs, if appropriately combined, make it possible to obtain a very varied range of different white tones, also reducing consumption and guaranteeing control flexibility unthinkable with the sources currently installed.

This flexibility also allows you to enter a very thorny environment, that of coloured light on cultural heritage.

Time is not particularly lenient with colour pigments and history, often presents us colourless works of art; and we are used to this, to the point that thinking that once they were coloured leads us almost to feel uncomfortable. Many of the great Greek works like the Parthenon were not at white; the colours were saturated, and often materials like copper, silver and glass paste were used to make the finishes even more vivid.

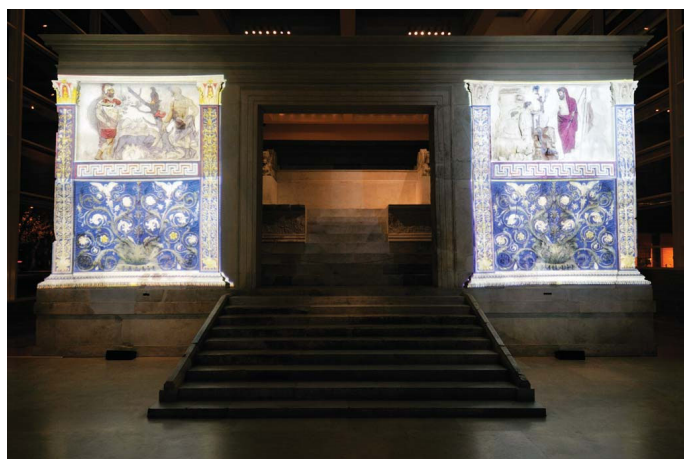


Fig. 2. The coloured light projection simulates the appearance of ancient colour on the Ara Pacis in Rome (2008).

Even the Ara Pacis in Rome was colourful; in 2008 an experiment (Figure 2), sponsored by Martin Professional, a luminaire manufacturer, coloured the bas-reliefs with light, using a gobo (transmissive glass disk, in that case, coloured) for reproducing its ancestral appearance (Rossini 2010).

The attempt was rather coarse and not precise; however, it had the great merit of creating a particular resonance and of being a precursor to more recent reconstructions (with advanced technologies, such as augmented reality) that are still discussed today.

Piazza del Nettuno was surely not as colourful as the Ara Pacis was; however, the use of colour on cultural heritage has been used from time to time. Just think of the coloured lighting of the Castello Sforzesco in Milan (Figure 3) by Duilio Passariello, which caused many criticism (like the one of the Italian writer Umberto Eco) and then abandoned in favour of a more reassuring warm white light.

The radical modification of the colour of the lighting is a much-discussed topic, especially today that the more efficient solid-state systems are supplanting the old systems with discharge lamps. Even the only change in the colour temperature, perhaps accompanied by better Colour Rendering Index, is enough to trigger fierce criticism from the inhabitants and field experts (like the recent cases of Rome and Modica in Sicily).

Fortunately, however, the new control systems allow us to design a light that is still over time, allowing the possibility to use colour (even just change the shades of white) for certain occasions and for a specific time; to produce the so-called “wow-effect”, but to bring the situation back to normal, avoiding to definitively misrepresent the space.



Fig. 3. Lights at Castello Sforzesco in Milan (Italy). The installation received the critics (Colonnetti 2001) by many cultural figures such as Umberto Eco (writer), Arnaldo Pomodoro (sculptor), Emilio Tadini (painter and writer) and Carlo Bertelli (art historian).

### 4. The proposals

Already identified in the survey phase, the two privileged directions of observation coincide with the routes that tourists and users of the square usually follow: the first



route is the one that goes from Piazza Maggiore to Via Rizzoli, while the second is the one that goes from Via Rizzoli to Piazza Maggiore. The identification of these routes is essential both for the design of significant and visible lighting effects for most users, and for the evaluation of the parameters of quality of the system, such as containment of glare for the main directions of view of the observers.

#### 4.1. The lighting of the statue and the pedestal

It was not possible to provide lighting from below (with submerged luminaires) due to the structural problems of the basin. Therefore, the first concepts presented all had an illumination from above (from the walls of the buildings), preserving the concept of projection of the shadow already existing. The connotation of the square given by this effect is such that it was thought to reinforce the concept, using three-point lighting and producing three sharp shadows (instead of one) on the surrounding walls. However, the municipality had the desire to remove the shadow to contain the glare and therefore, in the final concept, we agreed not to cast any shadows on the walls.

The lighting with three projectors (positioned on brackets mounted on the Palazzo D'Accursio and the Palazzo del Podestà) has nevertheless remained, to increase the luminance of the statue, but providing a system of custom barn doors to contain glare for those who look at the statue against the light.



Fig. 4. Digital photo-elaboration of a daytime picture of the complex to simulate the lighting in one of the early concepts (shadows were later eliminated).

Four warm-light projectors (Wide flood 50°, 24W / 3400lm COB LED with colour temperature of 3000 K) have also been proposed, which will be aimed at the pedestal (the *Castellum*); three of these projectors are mounted on the same structures that support the projectors of the statue, while the fourth will be positioned on the wall of the entrance courtyard of Palazzo di Re Enzo. The three projectors used to light the statue will have a cooler colour

temperature (Narrow spot 10°, 35W / 5000lm COB LED with colour temperature of 5000 K), which will ensure greater prominence to the bronze structure. In this way, the contrast with the *Castellum* (in marble) will be even more marked. Cold light for the God of the sea and warm light for the earth on which he stands.

In addition to the regular white light, three RGB projectors (red, green and blue, 27.45W / 963lm) will be installed in the same position as the white light projectors that make up the Neptune's accent light, to provide temporary coloured lighting for events such as events:

- Blue lighting for World Diabetes Day in mid-November.
- Blue lighting for the World Autism Awareness Day at the beginning of April.
- Pink lighting for Komen Italia breast cancer day at the end of September.
- Red lighting for World Blood Donor Day in mid-June.
- Purple lighting for World Epilepsy Day at the beginning of February.

For the coloured light fixtures as well, we planned the installation of adjustable shielding systems for better control and definition of the beam related to the silhouette of the statue.



Fig. 5. 3D Simulation of the RGB Lighting of the complex. Digital reconstruction of the area was necessary to present the idea to the municipality.

Since some of the scenarios obtained with the coloured lights will lead the statue to have very low luminance levels compared to lighting with white light, it was decided that to make more visible the Neptune compared to the context, when using RGB projectors, the fixtures that illuminate the *Castellum* will be kept off, as visible in Figure 5.



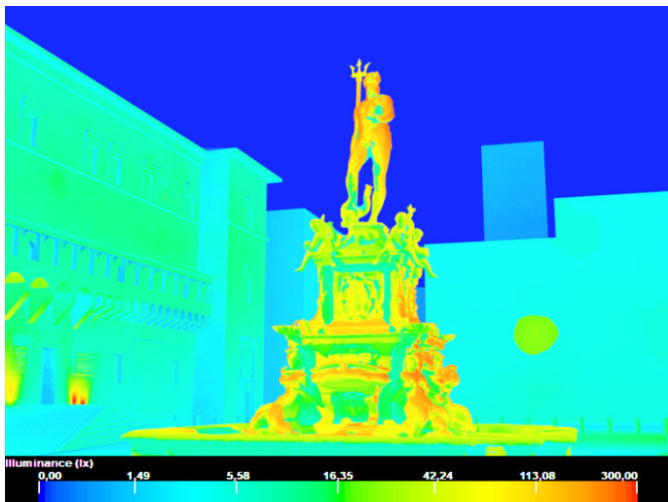


Fig. 6. 3D Simulation of the illuminance levels looking at the complex in the direction of via Rizzoli.

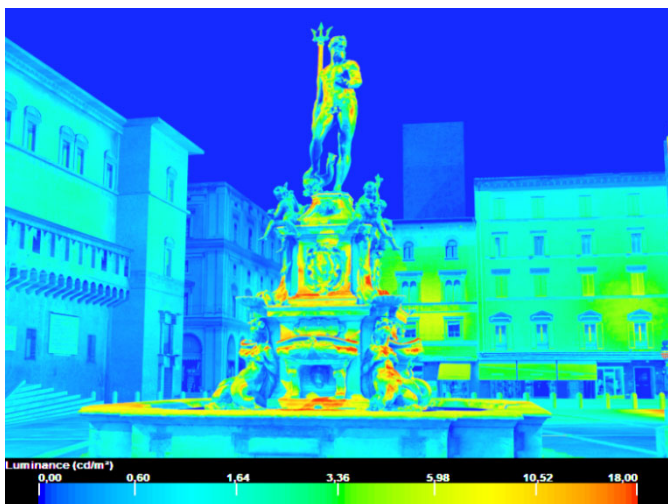


Fig. 7. 3D Simulation of the predicted luminance levels looking at the complex in the direction of via Rizzoli. The luminance levels of the actually installed luminaires average around 5 cd/m<sup>2</sup>.

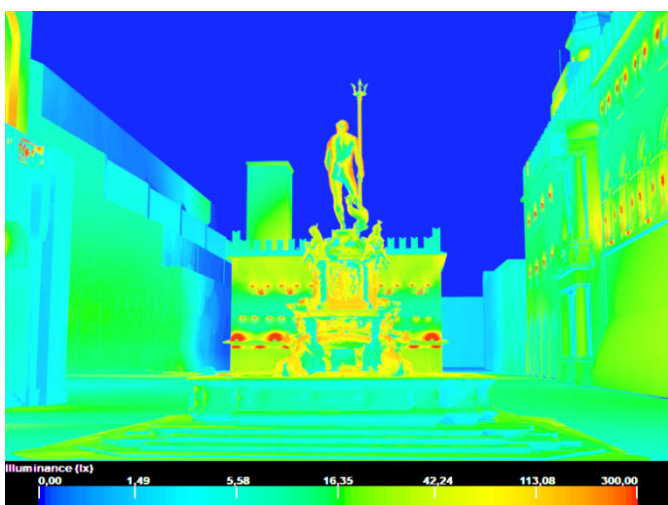


Fig. 8. 3D Simulation of the illuminance levels looking at the complex in the direction of piazza Maggiore.

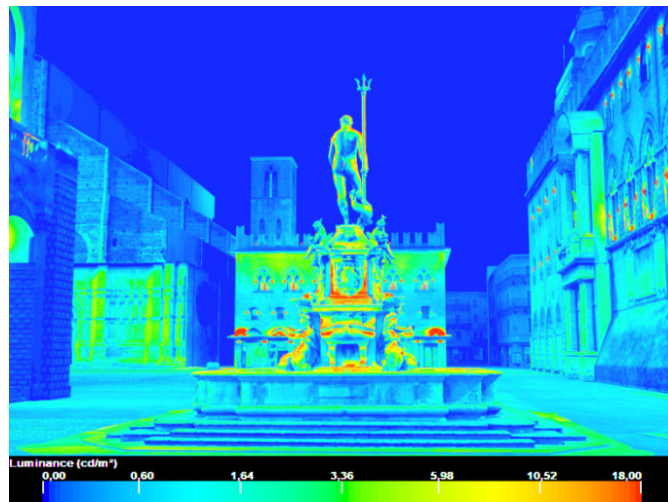


Fig. 9. 3D Simulation of the predicted luminance levels looking at the complex in the direction of piazza Maggiore. The luminance levels of the actually installed luminaires average around 5 cd/m<sup>2</sup>.

#### 4.2. Additional lighting of the spaces surrounding the fountain

In addition to restoring the functionality of the current lighting systems of buildings (projectors on the façades, light points on the windows, etc.) was also developed a proposal for the lighting of the spaces surrounding the fountain which consisted of a series of light signs placed on the floor in correspondence with the lines of white stone inserted in the flooring. These devices will emit a very controlled luminous flux (narrow blades of light 4,7W / 360lm), a sign of light to channel the attention of passers-by. The colour temperature chosen is neutral (4000 K). Some of the initial concepts provided for a large number of these light elements (and an RGB version of them) but, although these would guarantee great flexibility of use, in the end, we opted for a system of light lines that created a sort of corridor that ideally directs pedestrians towards Neptune. The aim is to create a dynamic perceptual context aimed at placing the complex at the centre of the hierarchies of visual perception of the area. In addition to the luminous signs on the walking surface, the windows of Palazzo D'Accursio (in correspondence with the Salaborsa Library) and the battlements of Palazzo di Re Enzo will also be lit. These additional lighting fixtures (narrow beam at 5.7W / 720lm, to illuminate only the profiles of the elements) will also, have a colour temperature of 4000 K.



Fig. 10. 3D Simulation of the Lighting of the complex. It is possible to observe the light hypothesised for the battlements.

#### 4.3. Lighting Management System

The luminaires for the statue and the adjacent areas were all based on LED Technology; this allowed us to have maximum control over them. For the entire system, we hypothesised the installation of a management system capable of ensuring the achievement of the following objectives:

- Possibility of creating predefined lighting scenes that can be selected by the operator for events/recurrence;
- Dimming and partial shutdown of the system in the late hours of the night to contain operating costs;
- Possibility to create new light scenes in case of special needs, through the composition and regulation of the lighting of the individual elements of the fountain, statue or square.

For this application, the choice of the protocol for the management system leads to some possible options: DALI, DMX or a hybrid solution. A control system with a simplified interface (to make the programming of the scenes accessible) would guarantee additional and innovative functions for dynamic lighting, which would allow the Municipality to assign new and changing perceptual values to the context, depending on particular situations (Di Salvo 2014).

#### 5. Conclusions

The main purpose of the work carried out was to provide the municipality of Bologna with ideas for enhancing the monumental complex, with contained costs and a low energy consumption. The designed sources have a much longer duration than those currently installed and, being

easily controllable digitally, they allow programming of on and off cycles optimised with the time of day, the period of the year, and many other factors. With the new control systems and a specifically customised user interface, it is possible to offer the municipality a tool to make the monumental complex of Neptune, a veritable scenographic element, easily controllable and scalable for festivals and events that can take place on-site; all without sacrificing classic white lighting, designed to enhance colors, shapes and materials, limiting glare towards passers-by and guarantee a good usability of the cultural site.

#### 6. Conflict of interest declaration

The author declares that nothing has affected his objectivity or independence in the production of this work. Neither the author nor his immediate family member has any financial interest in the people, topics or companies involved by this article. Neither the author nor his immediate family member had a professional relationship with the people and companies cited in this article. Neither the author nor his immediate family member is involved in a legal dispute with the people and the companies cited in this article. No conflict of interest including financial, personal or other relationship with other people and organization within three years of beginning the submitted work that could inappropriately influence, or be perceived to influence, this work.

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**Andrea Siniscalco** - MSc in Industrial design in 2002. PhD in design and methods of Product development in 2007. Vice-director and teacher in the master in Lighting Design & LED Technology of Politecnico di Milano. Teacher of lighting theory at the School of Design. Vice president of GdC - Associazione Italiana Colore. Fields of interest are lighting design, visual perception and colour.

#### References

Colonetti, A. (2001) 'I limiti della città - Serve uno spazio per dare più visibilità al sistema design.', *Corriere Design*, 3, p. 1.

Comune di Bologna (2019) Turismo a Bologna, ecco com'è stato il 2018. Available at: <http://www.comune.bologna.it/news/turismo-bologna-ecco-com-stato-il-2018> (Accessed: 11 October 2019).

Di Salvo, S. (2014) 'Innovation in lighting for enhancing the appreciation and preservation of archaeological heritage', *Journal of Cultural Heritage*, 15(2), pp. 209–212. doi: 10.1016/j.culher.2013.03.001.

EN 13201\_02:2004 "Road lighting - Part 2: Performance requirements".

Fotios, S. and Gibbons, R. (2018) 'Road lighting research for drivers and pedestrians: The basis of luminance and illuminance recommendations', *Lighting Research & Technology*, 50(1), pp. 154–186. doi: 10.1177/1477153517739055.

Rea, M., Bullough, J. and Akashi, Y. (2009) 'Several views of metal halide and high-pressure sodium lighting for outdoor applications', *Lighting Research & Technology*, 41(4), pp. 297–320. doi: 10.1177/1477153509102342.

Richard J. Tuttle (2015) *The Neptune Fountain in Bologna - Bronze, Marble, and Water in the Making of a Papal City*. Turnhout, Belgium: Harvey Miller.

Rossini O. (2010). I colori dell'Ara Pacis. Storia di un esperimento. *Archeomatica*, 1(3), 20-25.

UNESCO (2019) World Heritage Center. Available at: <https://whc.unesco.org> (Accessed: 11 October 2019).

UNI 11248:2012 "Illuminazione stradale - Selezione delle categorie illuminotecniche".

# Evaluation of the perceived colour difference under different lighting for museum applications

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## **ABSTRACT**

The role of lighting in museums has a fundamental importance. Light influences the perception of colours and space in the collections on display, therefore, any type of lighting must be adequately analysed to confirm the suitability and undistorted colour rendering of the illuminated objects. A two-stage perceptual test was carried out for this purpose. Initially, the participants were asked to evaluate the illuminants according to criteria such as: the brilliance of the colours, the degree of pleasantness of the lighting and the degree of overall satisfaction of the setting. Subsequently, the efficiency of different illuminants for the identification of colour differences between two objects was tested. The results obtained were then compared with the most commonly used colour rendering and colour difference indicators in order to determine their potential and limits.

**KEYWORDS** Lighting, Colour Perception, CRI, Museum Lighting

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## 1. Introduction

In museums, the role of lighting is often linked to the creation of an immersive and evocative experience for the viewer when visiting the collections. In this context, although the regulations for lighting that does not cause damage to the illuminated objects and to the users are respected, often the lights are not subjected to an analysis that confirms their adequacy and ensures a correct color rendering of the objects on display (Feller 1968, Camuffo 2014).

The experiment we are presenting can be divided into two main parts: evaluation of light sources and evaluation of colour differences.

In recent years, several experiments have been carried out in order to evaluate the perception of the colour of museum objects under different light sources (Boissard & Fontoynt, 2009, Pinto et al. 2008, Pinto et al. 2006, Scuello et al. 2004), focusing primarily on colour temperature and the study of LEDs. Nevertheless, it is difficult to integrate the elaboration of the visual system in the calculation of the colour perception and often it is reduced to evaluating a source based only on emission and reflectance spectra.

For this reason, it was decided to have users evaluate three main characteristics of the colour rendering: the brilliance of the colours, the pleasantness in relation to the lighting and the degree of overall satisfaction of the set-up. The aim of the brilliance assessment is to determine how much the illuminant promotes the colour rendering of an object on display. The term pleasantness refers to the illuminant and is designed to determine which light is most pleasing to the viewer, not considering, therefore, the color rendering of the object. Finally, with the term satisfaction, we ask you to evaluate the entire installation.

In addition to illuminants, the study of colour rendering in museums in recent years has also been the subject of many studies, aimed at determining which source guarantees better colour rendering and, if there are preferable sources, for the lighting of specific museum objects (Viénot et al. 2011, Nascimento & Masuda 2012, Nascimento & Masuda 2014, Vázquez et al. 2012). In this context, in the second part of the experiment, users were asked to compare the colours of two Colour Checkers (see section 2), to determine how much the illuminant influences the perception of colour differences.

The results of these two experiments were compared with the most common colour rendering and colour difference indexes. The aim of this study is to demonstrate that colour rendering is a complex concept in its definition and that the most common indexes are not enough effective to represent the perceptual variations of colour. The

applicability of the results obtained has been evaluated in the light of a complex field of application such as that of the museum, where for an exhibition lighting must be considered in terms of conservation, exhibition and use. In addition, the limits of colorimetric measurements, which are not reliable in the presence of spatial arrangements and different lighting conditions, are to be highlighted.

## 2. Materials and Methods

For this experiment, the use of the Gretag Macbeth Colour Checker, in original and printed version (Figure 2a), using a printer LaserJet Pro 400 colour. Both Colour Checkers have been positioned within a Light Booth, model The Judge II, equipped with 4 different types of light sources: CIE D65, Cool White Fluorescent, U30TL84 and Illuminant A. Two LED lights have been added to the Light Booth: one 'cold' (LED 1, 5000K) and one 'warm' (LED 2, 2500K). The uniformity of the light diffusion was verified on the basis of the Light Booth for all the lights.

The emission spectra of each individual source were measured with a CL-500A spectrophotometer (spectra in Figure 1, measurement set-up in Figure 2b) which, during the measurements, was placed in the centre of the Light Booth on the same support as the Colour Checkers. From the emission spectra of the sources the following were calculated: CRI (Colour Rendering Index) (Oleari, 1998), TM-30 Fidelity Index and TM-30 Gamut Index (Society, 2018).

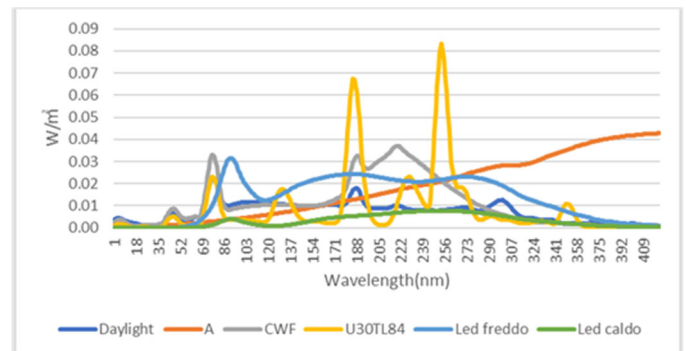


Fig. 1. Emission spectra of illuminants

The reflectance spectra of the patches of the two versions of the Colour Checker were measured using an Ocean Optics HR4000 spectrophotometer. The data thus obtained were then processed to obtain the colorimetric values in the  $L^*a^*b^*$  colour space by simulating the illumination under the various light sources present in the Light Booth. Finally, the chromatic differences (values  $\Delta E$  and  $\Delta E_{00}$ ) between the patches of the original Colour Checker and the corresponding ones of the printout were calculated.

The perceptual test was carried out on 20 people, none of whom had problems with colour perception.

The test, performed inside a dark room (Figure 3) without windows and without artificial lights on except for the Light Booth, was carried out in two parts:

a) Evaluation of the light sources: with the use of a guided table it was asked to indicate with an evaluation from 0 to 100 the brilliance of the colours, the degree of pleasantness referred to the light source and the degree of general satisfaction of the setting. The term brilliance was used because in the common language it is associated with the perceived brightness of the colours. It was decided not to use the term saturation or tone, as it is particularly specific and difficult for non-experts to understand.

This operation has been done alternating for each source, the original Colour Checker (McCamy et al. 1976, Pascale 2006) to the printed one so as to avoid that the judgment was subject to comparison between the two.



Fig. 2. (top) Original (left) and printed (right) colour checker inside the Light Booth. (bottom) Set-up of the CL-500A spectrophotometer during measurements.

b) Evaluation of colour differences: it was asked to indicate with an evaluation from 1 to 5, (where 1=identical patches and 5=absolutely different patches), the colour difference between 15 selected patches of the original colour checker and the corresponding printed patches

(Figure 4) (McCamy et al. 1976, Pascale 2006). This subjective colour difference assessment was carried out under all Light Booth sources. To solve the numerical problem of estimating the magnitude between different colors, the "Neutrals" tab of the Munsell Book of Colours was used as a framework. For example, the magnitude between patches N9 (white) and patches N7/N8 (light grey) corresponds to a difference of 1, while patches N9 and N3/N2 (dark grey) have a difference of 3.

### 3. Results

#### 3.1. Evaluation of light sources

The table below shows the CRI, colour temperature and TM-30 values of the Fidelity Index (Table 1). Figure 5 shows the results of the subjective evaluation of brilliance, pleasantness and satisfaction for each individual source.

	Daylight	A	CWF	U30TL84	LED 1	LED 2
CRI (Ra)	94	99	59	87	94	83
T colour(K)	7000	2600	3900	3000	4800	3000
Fidelity Index (Rf)	94	99	67	82	93	84

Tab. 1. CRI (Ra), T colour, Rf values of the various illuminants.

#### 3.2. Evaluation of colour differences

The following table summarises the values  $\Delta E$  and  $\Delta E_{00}$  calculated from the reflectance spectra of each patch of the Colour Checker under all the sources present in the Light Booth (Figure 6). All calculated  $\Delta E$  values have been compared with the average of the values assigned by users as shown in Figure 7, Figure 8, Figure 9, Figure 10 and Figure 11 and Figure 12.

### 4. Discussion

The results of the perceptual test showed some discrepancies between the calculated indexes and the perceived values in the evaluation of illuminants and colour differences.

#### 4.1 Evaluation of illuminants

With regard to the assessments of brilliance, pleasantness and satisfaction, it is interesting to note that the scores awarded by users never reach the high scores awarded by the CRI index (Figure 5 and Table 1) (Fumagalli et al. 2013). The exception is the illuminant CWF of which the printed version of the Colour Checker has slightly lower perceptual values, but substantially similar, compared to those of the CRI, while the score assigned to the original version is higher.

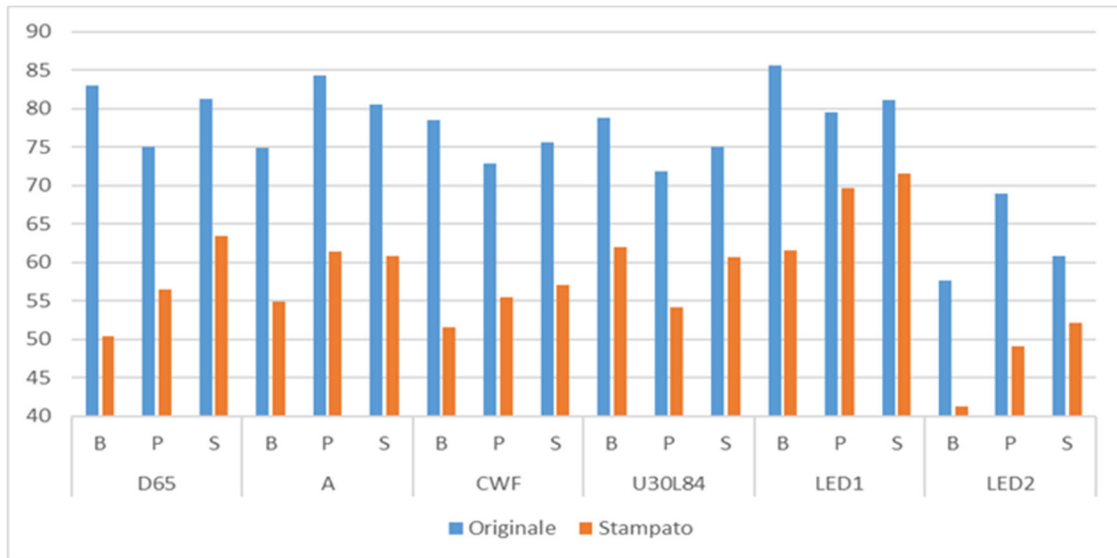


Fig. 3. User-assigned values in % for three parameters: B=Brilliance, P=Pleasantness, S=Satisfaction

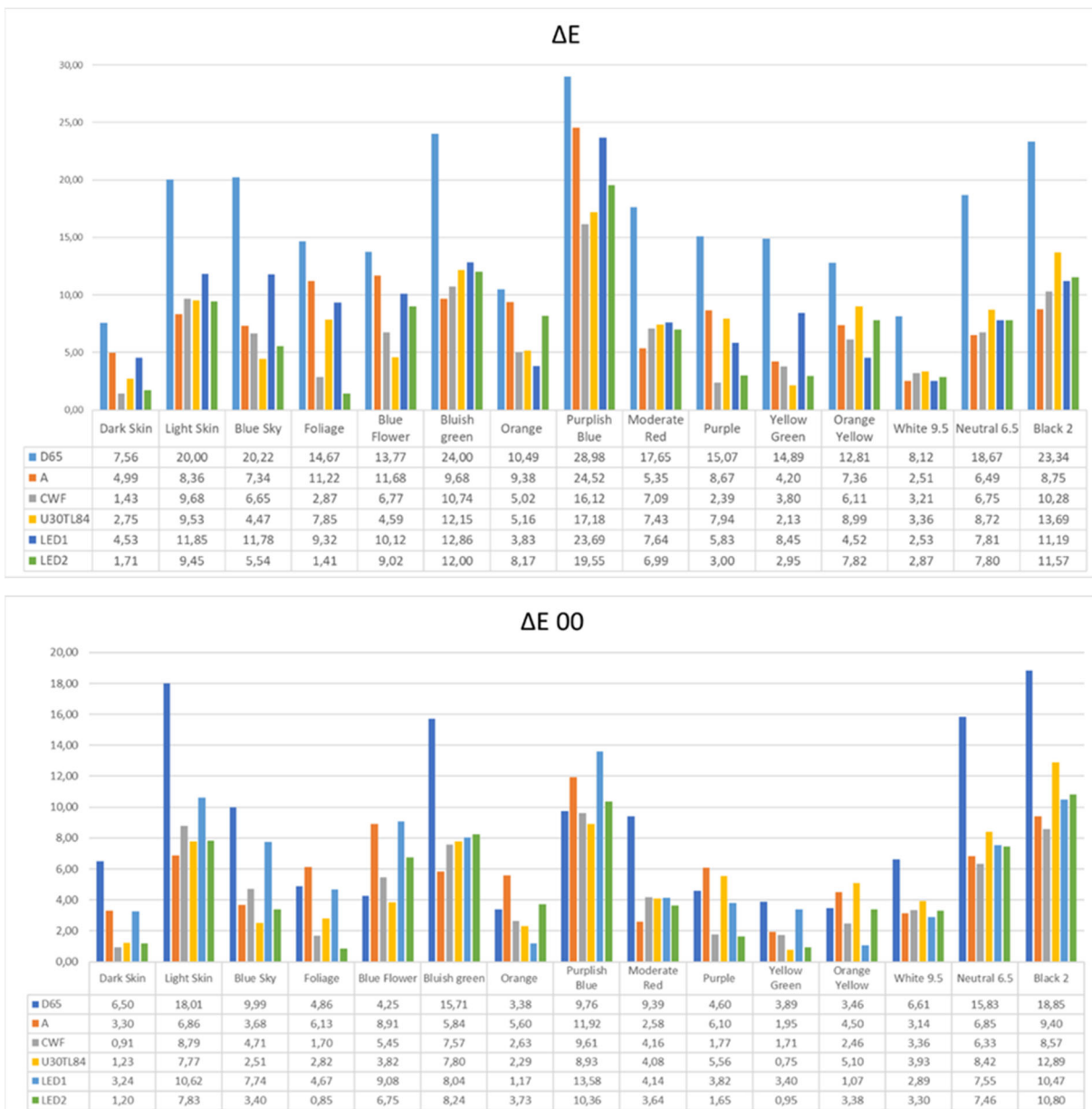


Fig. 4. ΔE (top) and ΔE00 (bottom) values calculated under the different illuminants in the Light Booth

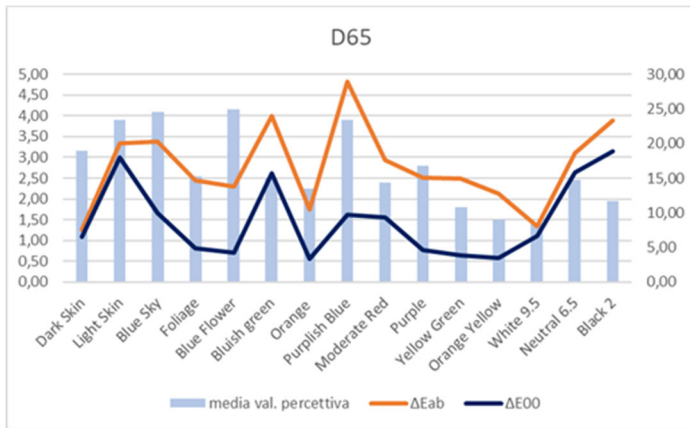


Fig. 5. Perceptual test values compared with the measured values of  $\Delta E$  and  $\Delta E00$  for illuminant D65.

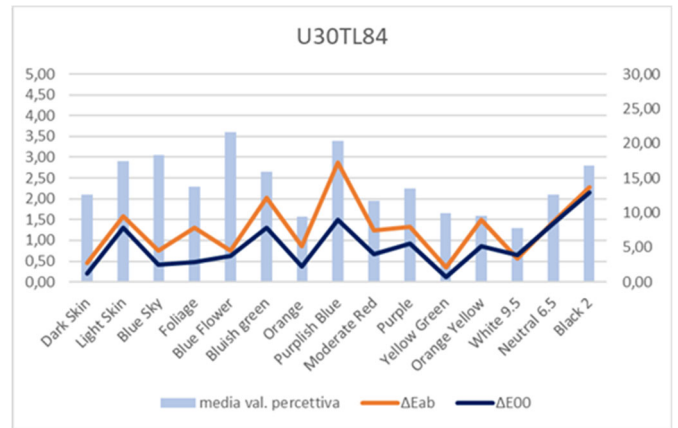


Fig. 8. Perceptual test values compared with the measured values of  $\Delta E$  and  $\Delta E00$  for the illuminant "U30TL84".

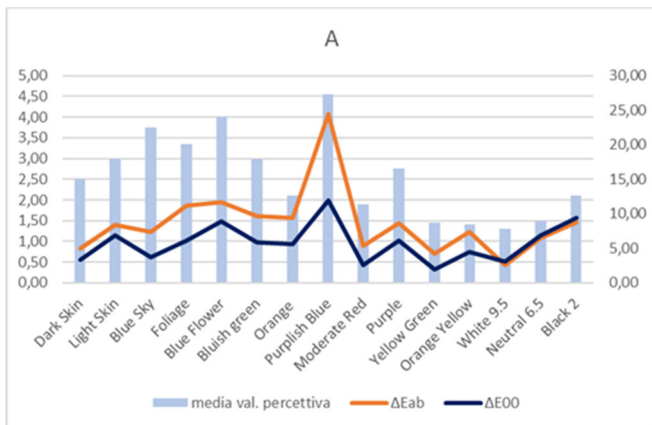


Fig. 6. Perceptual test values compared with the measured values of  $\Delta E$  and  $\Delta E00$  for illuminant "A".

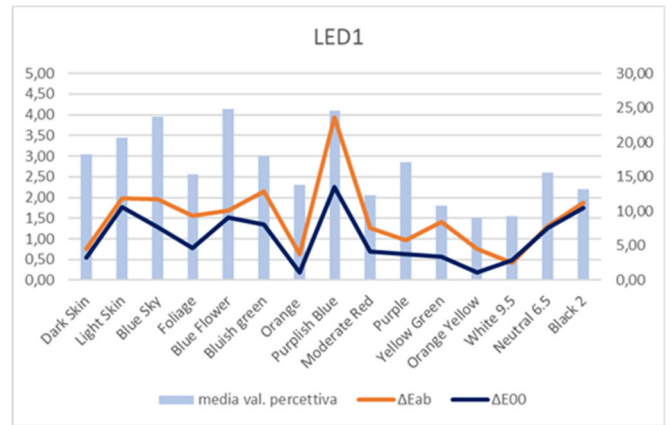


Fig. 9. Perceptual test values compared with the measured values of  $\Delta E$  and  $\Delta E00$  for the LED illuminant1.

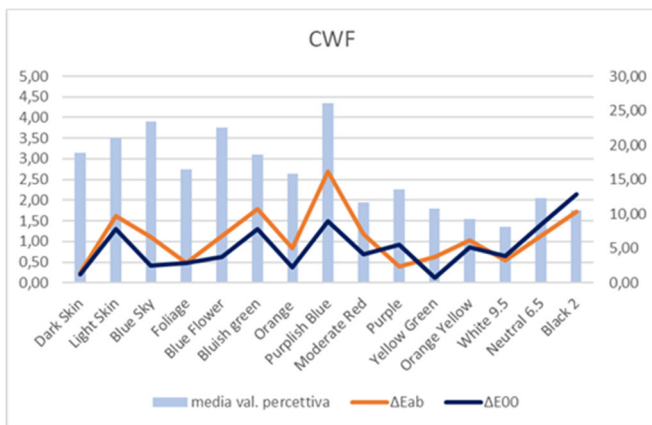


Fig. 7. Perceptual test values compared to measured values of  $\Delta E$  and  $\Delta E00$  for illuminant "CWF".

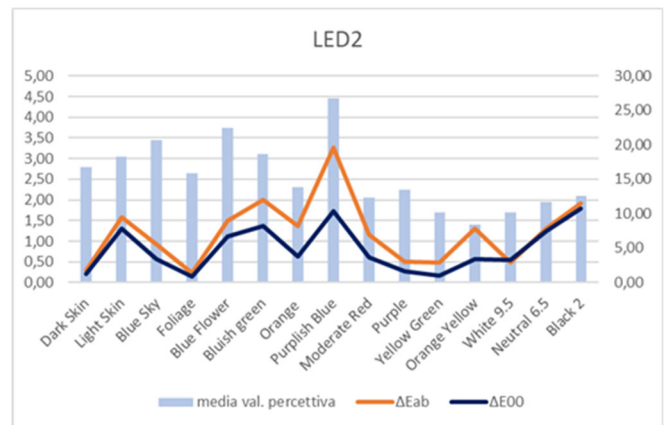


Fig. 10. Perceptual test values compared to measured values of  $\Delta E$  and  $\Delta E00$  for LED illuminant2.



It is clear that the original version of the Colour Checker under all illuminants is much more appreciated by users, who always give it very high scores, indicating that the support and materials used for any coloured object have a fundamental importance for good colour rendering.

Considering the overall satisfaction value, the illuminants that received the highest scores from users were illuminant D65, A and LED1. This evaluation is consistent with the values of CRI and TM-30 Fidelity, as these measurements also assign higher values to the illuminants themselves. Note that the LED1 scored high according to these two indexes because, being of the new generation, the emission spectrum was modified by the production company in order to meet the CRI index standardized by the CIE commission. In addition, the values assigned by the TM-30 Fidelity Index do not differ particularly from the CRI.

Considering the values of brilliance and pleasantness, there are major discrepancies between the subjective judgment and the colour rendering indexes. According to the brightness values, in fact, the LED1 has the highest value, followed by A, CWL and U30TL84 for the original Colour Checker, while for the printed version the highest brightness is given by the U30TL84 and LED1. Considering the pleasant lighting value for the original, the best illuminant is A, followed by LED1, while the printed LED1 obtains the highest scores, followed by A.

These results cast doubt on the colour rendering indexes, which do not consider the perceptual component of colour processing by the subjects, as well as the colour adaptation and spatial context variables.

#### **4.2. Evaluation of colour differences**

With regard to the measurement of colour differences ( $\Delta E$  and  $\Delta E_{00}$ ), it can be seen that in general the values are always high (except in specific cases), due to the characteristics of the substrate and the dyes that have very different reflectance spectra. The purpose of the experiment is to highlight under what conditions the colorimetric and precise measurement of  $\Delta E$  is not sufficient to determine the metering of two colours under different lighting conditions.

Considering the values of  $\Delta E$  and  $\Delta E_{00}$ , it is evident that the measured values are significantly higher for the illuminant D65. In addition, when comparing the individual patches, higher colour differences are obtained for those with higher blue components (Bluish Green, Purplish Blue, Blue Sky, Blue Flower) (Brueckner et al. 2009). When comparing the illuminants, CWF and LED2 maintain the smallest difference values.

The comparison between the various illuminants does not reveal a general predominance for the subjective values compared to those calculated but depending on the patch and the type of lighting, the results assume very different values. Despite this, it is noticeable that patches with a strong blue component, assume values of high colour differences, while they generally assume lower values both for patches with a strong red component (Orange and Moderate Red) and for those in shades of grey (White 9.5, Neutral 6.5, Black 2), with a few exceptions.

Patches with a strong red component and patches in shades of grey obtained lower values both in the calculated  $\Delta E$  and in comparison, to the scores assigned to all the others.

Considering illuminant D65 (Figure 7), the differences noted by the subjects are always greater than 2, with a peak of difference for the Purplish Blue that assumes values close to 5. Looking at the values for the illuminant A (Figure 8), there is a general decrease in the values of subjective difference, so the peak for patch 10 remains, but falling to a value of about 4.3. For White, Yellow Green and Moderate Red the difference values are close to 1.5 so they are considered perceptively very close to those of the original Colour Checker.

Considering the illuminant CWF (Figure 9), the values of Dark Skin and Purple are considered more similar to the original, while the colour difference of Purplish Blue returns to values of about 4.5. In this case the values of  $\Delta E$  and  $\Delta E_{00}$  are much lower than in the case of D65 and A.

As for U30TL84 (Figure 10) the difference for Yellow Green and Dark Skin is subjectively around 1.5 the values of  $\Delta E$  and  $\Delta E_{00}$  decrease for Purplish Blue but remains around 4.5 in subjective judgment. Finally, as far as LED1 (Figure 11) is concerned, the perceptual differences between the original and the printed one increase compared to the other illuminants and present a similar trend to D65, even if lowered by about 1 point. In LED2 (Figure 12) the subjective values are very similar to LED1, with some differences for some blue/green patches that have lower subjective values and some of the red-orange patches that have higher values.

From these evaluations and from the graphs we can see, therefore, a strong discrepancy between the  $\Delta E$  and  $\Delta E_{00}$  colorimetric values measured from the spectra to the perceptual values given by the evaluation of the subjects involved in the study, differences that are not given simply by a physical component of reflectance compared to an illuminant, but by a strong perceptual component. This is because both measurements  $\Delta E$  and  $\Delta E_{00}$  do not consider the spatial arrangement of colours in the

evaluation and adaptation of the human visual system to the different illuminants.

## **5. Conclusion**

In this study it is shown that the colour rendering indexes are not adequate to give an estimate of the perceptible rendering of an illuminating and to maintain metamerism. Moreover, it has been demonstrated that a colorimetric measure of local colour difference is not sufficient to represent the perceptual variations of colour with the variation of illuminants and in the presence of a spatial arrangement.

A further limitation to these measures lies in the fact that they do not consider the colour adaptation of the human eye, the surrounding illumination and the signal processing by our visual system. This aspect can be seen above all from the answers to the perceptual test on colour differences where it became clear that some users had the ability to recognize and preserve the variations between two coloured patches even under different illuminants. Moreover, in most cases there was no correspondence between the values acquired with the experimental measures and those assigned by the perceptual test.

For applications in the museum environment, provided that the regulations for lighting that does not damage the objects on display and the users are respected, it can be seen that as far as lighting is concerned, the supports and materials used in the enjoyment of the exhibition will always be of greater importance, so the object will always be of primary powerlessness. Moreover, it has been seen that LED lights far exceed the D65 standard in the creation of a satisfactory exhibition space and for a pleasant and apparently correct reproduction of colours.

Moreover, when evaluating sources for complex exhibition spaces, it must be taken into account that both the CRI and the Fidelity Index do not consider the spatial arrangement and the systems for adapting the eye to lighting, so if only one of these aspects is taken into account in the evaluation methods without considering the others, the comparison between the data and reality can never be considered satisfactory.

In conclusion, since many differences have emerged between the perceptual test and the values measured experimentally, both regarding CRI,  $\Delta E$  and  $\Delta E_{00}$ , it is considered necessary to reconsider the methods and uses of both parameters to ensure that they are more reliable and consistent with reality.

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## **6. Conflict of interest declaration**

The authors declare that there is no conflict of interest with other people or organizations.

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## References

- Boissard, S., & Fontoynt, M. (2009). Optimization of LED-based light blendings for object presentation. *Color Res. Appl.* 34, 310-320.
- Brueckner, S., Bodrogi, P., & Khahhn, Q. T. (2009). Colour Rendering of new white LED light sources - visual tests. *Lux Eurpoa*, pp. 397-404.
- Camuffo, D. (2014). *Microclimate for cultural heritage - Conservation, restoration, and maintenance of indoor and outdoor monuments*. Elsevier.
- Feller, R. L. (1968). Control of deteriorating effects of light on museum objects: heating effects of illumination by incandescent light. *Museum News. Technical Supplement*, 46(9), 33 - 47.
- Fumagalli, S., Bonanomi, C., & Rizzi, A. (2013). An experiment on the color rendering of different light sources. *Color Imaging XVIII: Displaying, Processing, Hardcopy and Applications, IS&T- SPIE Electronic Imaging*, 3-7- February 2013, San Francisco (USA).
- McCamy, C. S., Marcus, H., & Davidson, J. G. (1976). A Color Rendition Chart. *Journal of Applied Photographic Engineering* 11 (3), pp. 95-99.
- Nascimento, S. M., & Masuda, O. (2012). Psychophysical optimization of lighting spectra for naturalness, preference, and chromatic diversity. *JOSA A*, 29(2), A144-A151.
- Nascimento, S. M., & Masuda, O. (2014). Best lighting for visual appreciation of artistic paintings—experiments with real paintings and real illumination. *JOSA A*, 31(4), A214-A219.
- Oleari, C. (1998). *Misurare il colore*. Hoepli.
- Pascale, D. (2006). *RGB Coordinates of the Macbeth ColorChecker*.
- Pinto, P. D., Linhares, J. M., & Nascimento, S. M. (2008). Correlated color temperature preferred by observers for illumination of artistic paintings. *JOSA A*, 25(3), 623-630.
- Pinto, P. D., Linhares, J. M., Carvalhal, J. A., & Nascimento, S. M. (2006). Psychophysical estimation of the best illumination for appreciation of Renaissance paintings. *Visual Neuroscience*, 23, 669-674.
- Scuello, M., Abramov, I., Gordon, J., & Weintraub, S. (2004). Museum lighting: Optimizing the illuminant. *Color Res. Appl.*, 29, 121-127.
- Society, I. E. (2018). *IES Methods for Evaluating Light Source Color Rendition*. ISBN-13: 978-87995-379-9.
- Vázquez, D., De Luna, J. M., Alvarez, A., Sánchez, A., & Sedano, U. (2012). Study of chromatic variations between metameres by varying the lighting in the painting "Boy in a turban holding a nosegay. *Optical Systems Design, International Society for Optics and Photonics*, 8550.
- Viénot, F., Coron, G., & Lavédrine, B. (2011). LEDs as a tool to enhance faded colours of museums artefacts. *Journal of Cultural Heritage*. 12(4), 431-440.

# BOOK REVIEW: Nature & Colour - New perspectives on dyeing.

Renata Pompas

**Ennia Visentin: NATURE & COLOUR - New perspectives on dyeing.** "Lis Aganis" Eco Museum of the Friulian Dolomites. Maniago (PN), 2019. (pages 156).

Ennia Visentin is an expert in mural decoration, lecturer in pictorial decoration techniques and fresco, with a series of exhibitions to her credit.

Inspired by the renowned and seminal book by Franco Brunello (The art of dyeing in the history of mankind) in recent years she has devoted herself to the study of coloring substances used in natural dyes, the outcomes of which are described in this book. A very interesting book that combines the theoretical activity of study and research on primary sources described in ancient and contemporary texts, with accurate validation in the lab, documented by color slides inserted in the text.

An in-depth description of dyeing and its procedures is followed by a section which deals with a very current theme: the possibility of a new ethical-cultural paradigm, for an aware consumption of non-toxic and renewable materials, recovery and use of waste material.

## Part one – The art of dyeing

A concise description of the main and most relevant natural dyes used from prehistory to current times, which provides a comprehensive historical view, mostly within a European context.

## Part two – Dyeing processes

This is the most substantial section of the book which, beginning with the textile fibers and their preparation handling, describes the process of gathering and drying of plants, the different types of color dips and their final fixation.

- Direct dyeing, by immersion in water of the dye vegetable and of the untreated textile fibers.
- Mordant dyeing, by immersion in water of the dye plant and of the textile fibre treated with processing substances and additives.

- Single dip dyeing, in which mordanting and dyeing take place together.
- Layered dyeing, a vegetal print currently termed "eco-print".
- Multiple layer dyeing, through successive color dips, interposed by setting and drying of the fibers.
- Dyeing below boiling point, which enhances particularly some colors.
- Cold dip dyeing, which requires an extended processing time.
- Solar dyeing, which uses rainwater and exposure to the sun. These are the two topmost eco-sustainable processes.
- Fermentation dyeing, which is done by macerating fruits or lichens in water with alkaline substances.
- Different dyes with the same dip, with the same plant, with different pH: relative to different immersions of fibers in the same dyeing vat, with results that decrease down to the dullest shades of the last dip. Process used in antiquity to dye the people's cloth in the same dyeing bath used for more precious fabrics.
- Combination dyeing, where she demonstrates how the most vibrant greens have always been obtained combining two coloring substances.
- Developed Dyes, obtained by employing metallic salts.
- Paint dyeing, which entails an initial process of painting, followed by drying and then dyeing.
- Vat dyeing, process by which fibers and fabrics immersed in the dyebath take on their colouration only through exposure to air (oxidation), used in blue and purple dyeing.

## Part three – Dye plants

A selection of the main plants used for the ranges of reds, yellows, blues, of greens, browns, of blacks and intermediate shades obtained through combinations of colourants.

## Part four – When nature becomes art: dye plants and dye recipes

In this section, contextualising them with historical notes, she describes the plant, the extraction of pigment and



dye recipes of Madder (*Rubia tinctorum*) for reds, of Wild Mignonette (*Reseda lutea*) for yellows, of Woad (*Isatis tinctoria*) and Indigo (*Indigofera tinctoria*) for blues.

#### **Part five – Toward a new ethical-cultural paradigm**

This section, in which Ennia Visentin points out how the textile sector is considered the second most polluting in the world, seemed to me very new and worthy of note. She deals with the issue not only of developing natural dyes on eco-demo compatible fibers able to guarantee salubrity characteristics, but also with the recovery of marginal lands for cultivation and the reutilisation of waste products or by-products from the agricultural or agri-food sectors,

A research program has been carried out on “Local dye woods”, intended as being part of the Friulian region that supported her project: among other items the waste material from tree and shrub prunings were analysed and the dyeing with branches, bark and shavings or various scraps of walnut wood, cultivated and wild apple and fig, of which she provides recipes.

In conclusion the author hopes to succeed through her research in connecting single agricultural enterprise with artisan and tourist ventures, from the viewpoint of a circular economy, which forges a cultural product model and attention to social inclusion.

**The Bibliography** concludes the work.