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SMART HERITAGE: AN EASY METHOD FOR MATCHING COLORS

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ABSTRACT

In the field of built heritage conservation, conservators frequently face the task of faithfully reproduce -from a chromatic point of view- surfaces and paintings, often having small patches of original color as the only reference. The market provides conservators with effective and specific color measurement devices that enable them to capture, measure and quantify the color of a surface, providing reliable data.
Unfortunately, *in situ* and on scaffolding it is not common to use such sophisticated field-portable tools: as this kind of equipment is often designed for other purposes, its use in built heritage conservation usually necessitates testing and careful calibration. This step is often carried out by visual assessment instead: for this reason, such a procedure is strictly related to the sensitivity of the conservator.
The aim of this paper is to identify an intermediate solution, which would be more effective than visual assessment, easy to perform, and significantly less expensive than portable spectrophotometers.
For this purpose, in this essay a color chart and software - specifically designed for photography – were tested, in order to compare, measure and analyze differences in color reproduction in any color rendition system.
Then, data were tested by comparing them with those obtained by specifically designed equipment.
The results show that the method is able to provide relevant information on color matching, it is quick and easy to perform and definitely affordable, thus it could represent a smart alternative for built heritage conservation.

Keywords
Chromatic reintegration; Color matching; Wall paintings; Color chart.

1. INTRODUCTION

Professionals working in the field of cultural heritage often face the challenge of identifying, defining and comparing colors that they encounter in their daily practice [1].
The first factor to be taken into account is that color cannot be considered a physical quantity, because -by its nature- it is the result of sensations of the nervous system that also involve emotional and cultural aspects of the observer [2]. The sensitivity of the human eye to various light radiations is not constant for every wavelength, it varies from individual to individual, and it also depends on the type of illuminant.
Color is therefore dependent on perception and interpretation, and as such it is purely subjective.
The term colorimetry refers to the science of measuring the physical quantities that characterize color, regardless of the subjective response of the observer.
Colorimetry is based on the principle that the properties of the mechanisms responsible for color vision and the relationships between physical stimuli and the responses to these mechanisms, can be described. Through this language an observer can describe a color in a way that is unambiguous and unique [3].
Wyszecki and Stiles define colorimetry as the «branch of color science concerned with specifying numerically the color of a physically defined visual stimulus» [4].
All systems of colorimetry are required to be three-dimensional because of the nature of human vision: this means that the specification of three independent variables is required to describe colors uniquely.
The parameters that allow to identify a color are hue, saturation and lightness:

- Hue or color is the particular visual sensation produced in the observer by light radiation: for

light is composed of a mixture of several wavelengths, the hue corresponds to a specific intermediate wavelength, called the dominant wavelength.
- Chroma or saturation represents the feeling of the degree of concentration of the hue in relation to the white (or grey, or black) content. Saturation varies from values as low as 0% for very pale, almost white colors, to as high as 100%, the limit at which the color is given by the specific pure chromatic composition.
- Lightness (or brightness, or brilliance) indicates the intensity of the sensation of a color: it can be very dark or very bright, and can be measured independently of the hue.

Two colors displaying the same values of hue, saturation, and lightness are identical to the human eye. In 1931, the *Commission Internationale de l'Eclairage* (CIE, International Commission on Illumination) defined a standard chromaticity diagram that includes all the colors visible to the human eye. Like other color codings, this diagram is based on the use of three primary colors which, when mixed together in additive synthesis, make it possible to obtain all the colors existing in nature. However, unlike the RGB or CMYK methods (additive and subtractive synthesis), the chromaticity diagram proposed by the CIE does not depend on the behavior of a display or printing device but is based on the concept of Standard Observer. The Standard Observer is defined from the properties of our visual system and is based on systematic analyses of a large sample of human observers. The CIE system provides a standard procedure for describing a color stimulus in terms of defined illuminants and a defined standard observer.
Only by referring to a standardized method for expressing colors can the definition be immediate and objective [5].
One of the most widely used systems today is CIELab 1976, based on the subtractive synthesis. It is able to describe the entire range of colors perceived by the human eye better than any other color space in use -such as the RGB and CMYK systems- given that these are purely physical systems. In CIELab, E indicates color difference, C indicates the chromaticity difference (i.e. the difference in saturation between two shades of the same color) and L* refers to the brightness difference, while a* and b*, which can take on positive or negative values, describe the chromatic coordinates on the green-red and blue-yellow axes, respectively.

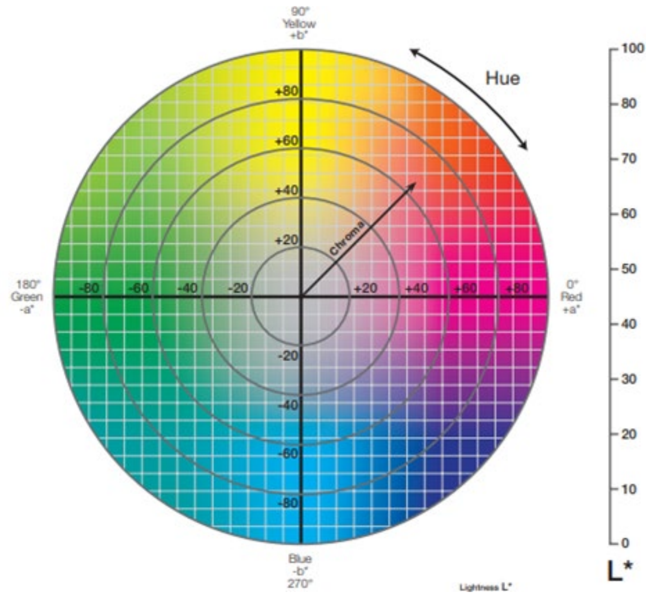

Figure 1 – CIELab color chart (Source: www.xrite.com).

The definition of the color of a paint layer can generally be approached and resolved using different procedures: the first step in identifying the appropriate methodology and instrument is to identify the nature of the problem and/or the purpose of the investigation.
Utilizing instrumental determination of painted surfaces can serve various purposes in the field of conservation: the objective description of alterations in color, caused by exposure to atmospheric agents or other chemical or physical factors, or the objective control of reference samples of color and color atlas, or even the evaluation of variations in color in the production of colored surfaces.
In this study, the objective is to get to the unambiguous description of differences in color between an original surface and a reference sample.

1.1 Color measurements

In some cases, color atlases can be used (such as Munsell's color system) that are based on direct visual comparison by observation under a specific light source between the reference sample and the object under investigation. This type of colorimetric analysis has the advantage of being immediate and not requiring any physical-mathematical theory on the part of the user. However, it presents a number of limitations: the color evaluation carried out by visual comparison of two colored bodies does not allow for taking into consideratiom the surface texture and the reflective

power of the investigated surface. Furthermore, overlapping layers of paint with different degrees of transparency can be found, which are difficult to reproduce and classify with color atlases. Finally, the color atlas system does not allow for quantifying of the difference found between two colors.
The analytical measuring of the chromatic parameters of surfaces in the field of cultural heritage is carried out by colorimeters and spectrophotometers.
The first tool refers to colorimetry, which is the numerical, three-dimensional specification of the visual stimulus for the sensation of color: a colorimeter is a device that mimics the way humans perceive colors.
Spectrophotometry is a non-invasive technique which measures the amount of light reflected or transmitted by a material at individual wavelengths of the spectrum. The optical instrument used to measure how materials reflect or transmit light is called a spectrophotometer.
The spectrophotometer measures the intensity of wavelengths in a light spectrum compared to the intensity of light from a standard source and returns it on a graph called spectral or spectrophotometric curve. The shapes of such curves are often specific for various colorants/pigments, providing a type of fingerprint characteristic of the chemical nature of the material [6].
Spectrophotometry and colorimetry can be useful in many important ways in objective analysis and research, and are commonly adopted for the examination of materials in cultural heritage.

1.2 State of the art and aims of the study

As a matter of fact, spectrophotometry and colorimetry are under-used in the field of cultural heritage conservation.
As spectrophotometers and colorimeters are often designed for other purposes, their use in built heritage conservation and for *in situ* analysis of wall paintings is often hampered [7].
In order to ensure accurate data, proper instrument calibration is necessary in first place, along with multiple testing and measurements to provide for statistically reliable results, recognition of the effect of sample characteristics on the method of analysis, and reference information.
The main limitations lie in the following points:

- The difficulty of having to use instrumentation created for industrial control, and designed for routine operations.
- Consequently, the difficulty of having to adapt this instrumentation to complex and continuously diversified patterns, such as those belonging to polychrome surfaces.
- The need for a technology capable of measuring very restricted areas, and even punctiform ones.
- The need to assure appropriate conditions of repeatability in uneven conditions, and even when using mobile equipment: the correct identification of the same points on a surface, which can be measured several times, has to be guaranteed, in order to obtain a scientifically correct comparison.
- Additionally, few conservation professionals have experience in colorimetry or access to professional equipment. Furthermore, what is to be taken into account is the economic aspect as well, which in many cases turns out to be the first limitation.
- Difficulties in overcoming these obstacles make colorimetric and spectrophotometric techniques a niche tool in conservation, generally reserved for scientific and study campaigns.
- But still, in preservation and conservation of historic facades - especially for those of buildings that are in use - conservators frequently face the task of faithfully repurpose surfaces and paintings from a chromatic point of view.

In most cases, given the difficulty of applying analytical techniques, this step is carried out by visual assessment by a conservator proficient in the field of colorant formulation and with in-depth knowledge of the behavior of colorants in a specific material: the process involves making a series of samples that are tested on the surface to be treated, in order to identify the most suitable ones.
However, this procedure is largely dependent on the sensitivity of the conservator.
From these discussions, one major conclusion is drawn: compromises must be made in order to obtain accurate assessment of color, that is essential in many applications.
The primary goals of the project are to identify an intermediate solution, which would be more effective than visual assessment, easy to perform, and significantly less expensive than spectrophotometry, and to establish a replicable methodology.

2. MATERIALS AND METHODS

The nature of the problem to be solved and the purpose of the measurement must first be defined before an instrument appropriate to the task can be selected: for

the measurement of opaque, uniform, dielectric (non-metallic) materials, most of the existing color-measuring instruments are adequate.
In this study, the aim of the evaluation is to objectively describe a colored surface, and to establish differences in color between an original surface and a reference sample: since the materials have identical colorant composition and surface characteristics, tristimulus filter colorimetry is an adequate technique, and there is no need for more sophisticated equipment.
For these reasons, the present study was addressed to the field of professional photography, and the use of a ColorChecker chart as reference tool for evaluating colors was investigated.
A uniform color field was taken as a reference for the study, and the data acquired from the color chart were tested by comparing them with those obtained by specifically designed equipment.

2.1 Instrumentation

The tool that was tested for this study is the X-Rite's Passport ColorChecker, a target specifically designed for photography and video production, that is able to compare, measure and analyze differences in color reproduction, in any color rendition system, through the related calibration software.
The Colorchecker – Color Rendition Chart was first designed and presented in 1976, in an article by C. S. McCamy and other members of the Machbeth company (Kollmorgen Corporation) [8]. It consists of a series of color patches (greyscale, primary colors, other "natural" colors). The pigments are selected to ensure maximum stability in time and a minimum degree of metamerism: the predefined colors of the Colorchecker vary uniformly with the natural colors when the light source changes, both when the comparison is direct and when a photographic image is taken into account [9].
Issued in 2009, the ColorChecker Passport replaced and enhanced the original chart. The ColorChecker Passport has three targets: a color chart, a large light-grey target for white balance, and a target with patches designed to neutralize or enhance global color shifts in images. The system includes a software to generate DNG Camera profiles from images of the ColorChecker, and it can be used as an Adobe Lightroom plug-in.
The instrument used as a reference is a Ci7000 series X-Rite benchtop reflectance spectrophotometer, paired with the Color iQC software.
Illumination was obtained by a D65 illuminating agent. Defined in 1964, D65 has become the standard solar illuminant reference (midday average daylight of the northern sky) for the industry as well as for various applications with a CCT of 6504K, described and used as a reference in ISO: 3668, ASTM 1729 and DIN6173-2. Finally, In order to guarantee that consecutive measurements have been made in the same area, a graduated mask was used.

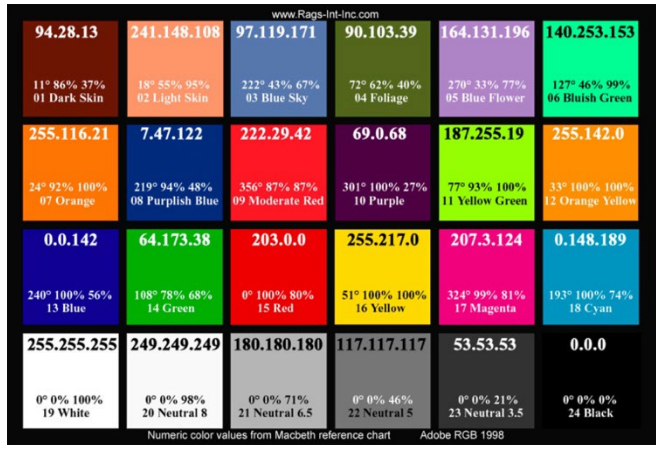

Figure 2 – Values of chromaticity coordinates of the Gretag Macbeth Color Checker (Source: www.xrite.com).

2.2 Color measurements

Two measurements of the same surface were taken, both with the reference spectrophotometer and by using the ColorChecker chart, in order to make a comparison. The first measurement was carried out with the spectrophotometer on a surface sample. The color was measured using a reflectance spectrophotometer according to the CIELab1976 color system. The characteristics of the color measuring instrument are the following: color scale CIELab; illuminant D65; standard observer 10°; geometry of measurement 45°/0°; spectral range 400–700 nm; spectral resolution 10 nm. Before taking measurements, the instrument was calibrated with the white reference tile supplied by X-Rite.
Then, the use of a digital camera paired with a color chart for colorimetry was investigated: the system consists of a digital camera (Panasonic Lumix GH5 + 14mm f/2.5), a ColorChecker Passport target and a source of light with a color temperature of 6500 K.
First, the white balance (WB) was setted by using the light-grey target provided by the ColorChecker. Then, a photograph of the surface was taken incorporating the ColorChecker card in the photographed scene, in the same lighting conditions.

Once the picture of the surface was taken, it was processed using the related calibration Passport ColorChecker software to balance colors by analyzing the chart patches in the resulting image, and to create a DNG custom color profile to be open in Adobe Camera Raw. This process allowed to measure the CIELab coordinates of the surface through the Adobe Photoshop Color Sampler tool.

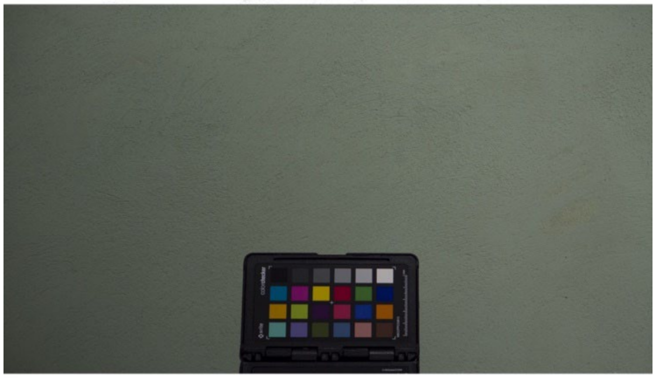

Figure 3 – Sample image taken in daylight.

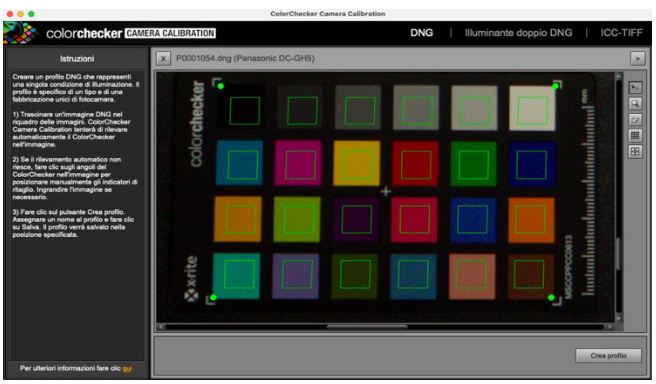

Figure 4 – Color profile creation via Colorchecker Camera Calibration software.

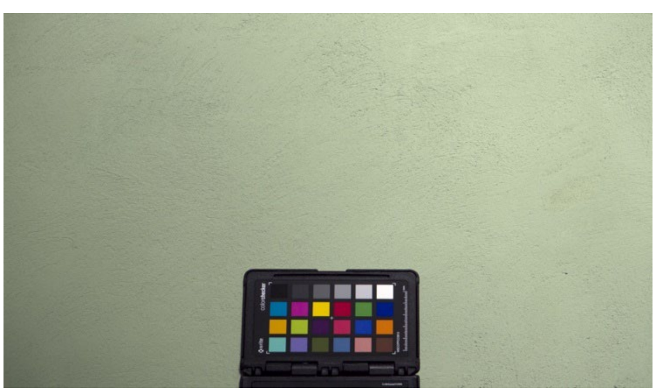

Figure 5 – Same image after WB and color calibration via Colorchecker Passport software.

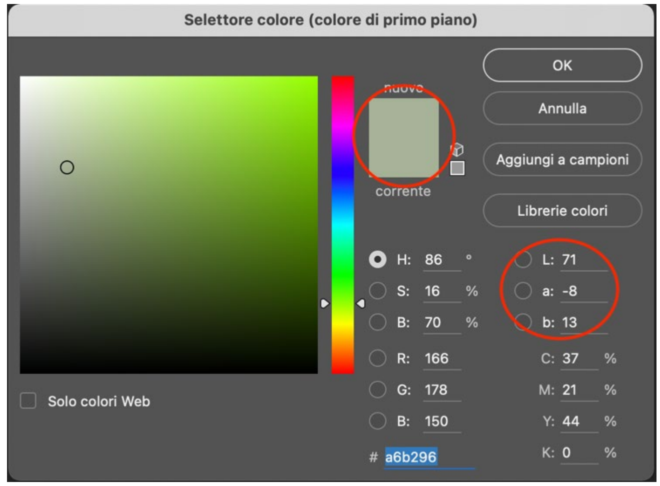

Figure 6 – Color coordinates through the Adobe Photoshop Color Sampler tool.

3. RESULTS AND DISCUSSION

All the results of the measurements were given in terms of CIELab color space values. The values in lightness (ΔL*), chromatic coordinates (Δa* and Δb*), and total color (ΔE*) were then calculated using these parameters according to EN 15886 (2010), i.e. the European standard describing the procedure to adopt for color measurement of cultural heritage objects using the CIELab method.
ΔE is an industry standard overseen by the International Commission on Illumination.

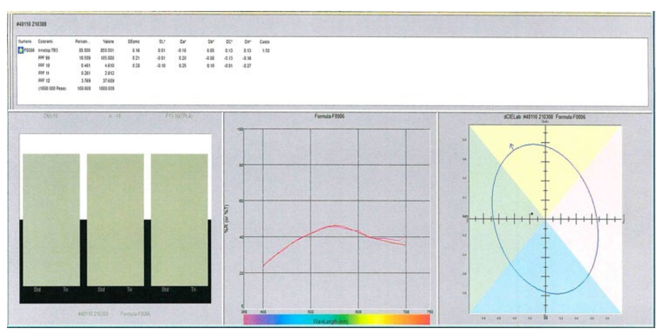

Figure 7 – Spectrophotometer output graphs. The black dot in the graph on the right indicates the accuracy of the result provided by the instrument (ΔE < 0.5).

The spectrophotometric analysis yielded the following results: in CIELab L* 71.77, a* -6.30, b* 11.05; in RGB 170 – 179 - 155; in CMYK 35% - 22% - 41% - 0%. The software also provided a color reproduction formula with a ΔE < 0.5, i.e. with a color variation from the

original painting that cannot be perceived by the human eye.
The ColorChecker method provided the following average results: CIELab L* 71.12, a* -8.57, b* 13.14; in RGB 166 - 178 – 150; in CMYK 38% - 20% - 45% - 0%.
The total color difference, ΔE*, between the two measurements (L^*_1 a^*_1 b^*_1 and L^*_2 a^*_2 b^*_2) is represented by the geometrical distance between their positions in CIELab color space.
It was calculated using the CIE76 color difference formula: $\Delta E^*_{ab} = \sqrt{(L^*_2 - L^*_1)^2 + (a^*_2 - a^*_1)^2 + (b^*_2 - b^*_1)^2}$
The measurement yielded the following result:

$$\Delta E_{ab} = \sqrt{} (71.77 - 71.12)^2 + (-6.3 - -8.57)^2 + (11.05 - 13.14)^2 = \mathbf{3.15}$$

This result shows that the two methodologies provided a very similar response.
On a typical scale, the ΔE value will range from 0 to 100; referring to the standard perception scale, this color difference is perceptible to the eye but is only slightly above the value 3, which is generally referred to as the threshold value above which the human eye can perceive color differences.

Table 1 – Chromaticity coordinates of the spectrophotometer and Colorchecker outputs

	Spectrophotometer output HEX (#): AAB39B
	CIELab 71.77 -6.30 11.05
	RGB 170 179 155
	CMYK 35% 22% 41% 0%
	Colorchecker output HEX (#): A6B296
	CIELab 71.12 -8.57 13.14
	RGB 166 178 150
	CMYK 38% 20% 45% 0%

4. CONCLUSIONS

The project presented here is a preliminary stage for the study of alternative methods for the colorimetric evaluation of opaque surfaces, such as those of wall paintings, in built heritage conservation.
The results obtained in this first step, although partial and provisional, suggest the method to be able to provide relevant information on color matching.
A major limitation to the practical application of spectrophotometric measurements in the field of conservation of built heritage is the availability for conservators of such sophisticated and expensive instrumentation, and the requirement of specific training - or professionals - for their use.
The Colorchecker method is based on the use of tools and software that are commonly used by conservators for other purposes, and therefore easy to perform, and definitely affordable.
The method proposed is not intended to replace spectrophotometric techniques, but to be applied as a smart alternative in peculiar situations where there is no access to specific equipment.
A number of considerations have to be made with regard to the replicability of the method on different surfaces and the behavior of the ColorChecker with regard to the phenomenon of metamerism, as well as with regard to the degree of accuracy of the measurements in carrying out the various steps.
Although these observations highlight the possible obstacles of the tested method and the limits of its applicability, this research is intended to be a feasibility study paving the way for more comprehensive and analytical research.

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