Chapter 3 Measuring colour in the artistic heritage field

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Abstract

The various aims of measuring colour in the artistic heritage field are described here. The first is "helping knowledge", i.e. increasing our knowledge of the materials contained in artefacts, like, for example XRF (X ray fluorescence) support measurements to identify the pigments used by a painter in a painting. The second aim is to record at a certain moment the colours in a work of art to memorise and document them for the future and this takes on particular importance with contemporary works of art. The third is how colour measurement can be of valuable assistance in checks made during restoration and cleaning operations. The final aim is the important one of conservation monitoring, that is being aware that a colour is changing before this is distinguishable by the usual methods, which send signals when it is by now too late. We also stop to look at measurement procedures and new potential ways of interpreting data. All this is illustrated with examples from real life experimental campaigns.

Keywords:

Artistic heritage, pigments, restoration, monitoring.

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1. Introduction

Colour is a question of perception and as such is not measurable. By "colour measurement" here we mean the measurement, in line with CIE standards, of the stimulus inducing perception. It is a question therefore of the absolute measurement of the radiation inducing the stimulus, a measurement normally obtained with a contact spectrophotocolorimeter with specular included and/or excluded in line with CIE procedures and expressing the sizes measured in space L*a*b*. The measuring is carried out in a point or "spot" with a diameter between 2 and 10 mm. depending on each case and within which the colour is considered homogeneous.

In the artistic heritage field measuring colour can have various aims and, of course, these can overlap. The first is "helping knowledge", i.e. increasing our knowledge of the materials contained in artefacts, like, for example XRF (X ray fluorescence) support measurements to identify the pigments used by a painter in a painting. The second aim could be to record at a certain moment the colours in a work of art to memorise them for the future and this takes on particular importance with contemporary works of art. The third is the fact that colour measurement can be of valuable assistance in checks made during restoration and cleaning operations. The final aim is the important one of conservation monitoring, that is being aware that a colour is changing before this is distinguishable by the usual methods, which send signals when it is by now too late. For any one of these aims it is in any case important to identify the measurement point and data filing procedures with a view in particular to the data being readable even in the distant future without there being any interpretational uncertainties

2. Helping knowledge

Many different types of technology have been used to research into the materials and implementation techniques in works of art with particular reference to paintings: from radiography and reflectography, to see what is below the surface, to XRF (X rays fluorescence) and Raman spectroscopy, for the identification of the pigments employed and multispectral analyses for identifying materials and painting techniques.

Figure 1. Radiography of the Caravaggio canvas "La buona ventura". The underlayer is an other painting. (measurements carried out by ENEA – National Agency for the Energy and the Environment)

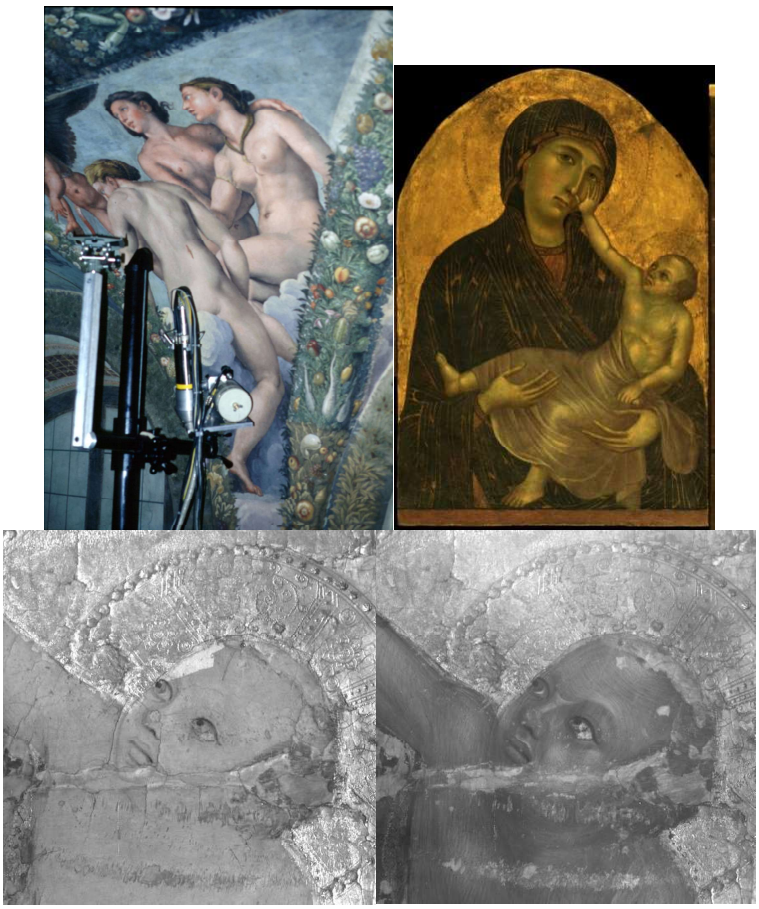

Figure 2. XRF measurements by ENEA – Loggia di Psiche, Raffaello fresco (up on the left) Multi NIR scanner. "Madonna with child" Cimabue, wood. (up on the right). Particular at λ = 850 nm (on the right) and at λ = 2265 (on the left) The differences found when reflecting different wavelengths are evident.(measurements carried out by INO – CRN).

But even the simple measuring of colour can be very important for understanding what went on. Let us consider a well-known case. Red ochre is a natural pigment but rarely a nice dark red. However, as Vitruvius wrote, it can be easily obtained from the more common yellow ochre.

"*… usta vero quae satis habet utilitatis in operi bus tectoriis sic temperatur. Glaeba silis boni coquitur ut sit in igni candens. Es autem aceto extinguitur et efficitur purpureo colour."*
".... about the burned ochre, very useful in wall painting, this is the preparation method: burn a piece of high quality "sil" until it is red hot and then make it cold with vinegar and it will be a dark red." (Vitruvius)

The presence, in the area around Vesuvius, of areas of plastered walls with yellow frescos transformed into red as a result of the temperature caused by the volcano is well-known and can be seen by any attentive visitor. These are of course walls frescoed with yellow ochre that got transformed to red because of the heat of the eruption. Herculaneum in particular was hit by a high temperature gas cloud.
There has recently been much research, and it is still continuing, into this transformation by parametrically studying the materials (the different types of ochre), temperatures, heating speeds, temperature residence times and so on. Measurements have also been made involving pieces of original plaster in order to compare the correctness of extrapolations with "real" measurements, that is with materials used in Roman plaster and even with fragments of original plaster.
Pompeian red is one colour or, rather, a range of colours. There is no precise definition from a colorimetric point of view neither as regards a reference table or as regards its coordinates. Some encyclopaedias or dictionaries define it as the "typical red used for the majority of the backgrounds in the wall paintings of Pompeii". Others engage in imprecise definitions like pigment defining it generically as a red obtained from compounds of mercury or iron (which is true if we are dealing with a certain type of ochre). Everyone knows that what is meant is that rather sombre red seen, as in fact several encyclopaedias say, in the majority of the backgrounds in the wall paintings in Pompeii.
Even if more systematic research is needed, based on, for example, measurements conducted on the walls of the Villa dei Papiri in Herculaneum (Fig. 3), from a colorimetric point of view it has been assumed that the areas definable as "Pompeian red" are in the following range of values L*a*b*:

35<L*<37, 21<a*<23, 15<b*<17, while for the walls definable as yellow the range is 53<L*<60, 14 <a*<16 and 32<b*<36.
The phenomenon of the transformation of yellow ochre into red ochre due to the heating up caused by the volcanic gases was measured in a quantitative sense. In this regard it should be remembered that, particularly in Herculaneum, the eruptions started with a gas cloud mixed with high temperature water vapour that took over the town before this was sealed by lapilli or lava and that this was the cause of the majority of the inhabitants' deaths. It has been assumed that a wall, originally yellow but now seen as red, underwent a transformation into red if this cover at least 70% of its surface.

Figure 3. Villa dei Papiri – Ercolano. The effect of the high temperature gas transforming yellow ochre to red ochre is evident. The crack in the wall also points to what happened. (by INO – CRN

The phenomenon is very significant and a large number of walls interpreted and seen as red were in reality yellow. Some interpretations of the Romans' architectural tastes, at least in Pompeii and Herculaneum, perhaps need to be revised or modified. The red part that was originally in reality yellow represents a considerable percentage of the total red that a visitor can see and this fact probably modifies the chromatic perception of the whole. There however need to be some objective assessments and therefore measurements conducted with colorimeters. Numerically, taking account of the L*a*b*

values chosen for defining "yellow" and "red" as indicated above, it turns out that 246 walls are currently assessed as being red versus 57 yellow ones, but originally there were 165 red ones versus 138 yellow.

3. Memorising the original colour

Spectrophotocolorimetry is a technique for indisputably identifying a colour in a particular point and indicating it with an internationally codified alphanumerical system.

Analyses of paintings are frequently requested, especially to verify the before and after where there has been restoration work, but what one would often like to know is the colour used by the painter originally before any restorations or deterioration, if this is the case. On most occasions it is possible, with a minimum impact on the painting, to identify the pigments used but an exact determination of the original colour, in terms of reflectance, chroma and saturation, has by now become impossible and the same applies to other parameters such as sheen.

If this is understandable for ancient paintings, it seems very strange that in the majority of cases there are no colorimetric analyses - with a memorisation of the data to avoid this very same problem reoccurring in the future - of modern paintings, which could instead be examined in a condition that is practically original and when at times one asks oneself whether such and such a white has not, perhaps after only a few years, become a little "yellowish".

Techniques such as photography, even if colorimetric and digital, are not suitable for memorising in files, in that they involve an initial acquisition that is complex and with a calibrated lighting system. The complete acquisition of an image could also lead on occasions to problems with the ownership of it as it is possible to reproduce it.

Numerical data indicating, in the final analysis, a physical property that can change over time, i.e. the ability of a material to reflect the electromagnetic waves of light in a particular point, are conceivably memorisable for ever.

We should point out that the technique we are talking about is cheap, has practically no impact and is extremely quick; about twenty different measuring points, which constitute a reasonable average for a painting of about 1 m^2, can be surveyed and memorised in about one hour. Moreover, once some valid operating instructions have been drawn up, the tests can also be performed by non-specialised personnel.

For this kind of file there does not need to be a good image quality but even a poor resolution in black and white is acceptable, provided that it is enough to give a precise indication of the points where the measurements have been carried out. Naturally these measurements should not be considered a

catalogue card but rather a sub-card or, better still, one of the various measurements necessary for compiling a complete catalogue card. The data acquired can, of course, also be used for a calibration of the colours should reproductions be needed.

As happens often in very many different fields, there is a problem of lack of contact, typical of two different cultures, between those putting together some research and/or a technique and those needing to use it in the sense that they are going to be the final user. In this case, between those involved in technological research applied to artistic heritage for the purpose of both enhancing our knowledge thereof and of conserving it and those given the task of studying a work for the purpose of conserving and enjoying it.

For the definition of the methodology and/or drawing up of a list of instructions, curators and art historians need of necessity to be involved for two reasons. The first is, as already said, that they are the final consignee. The second because without their experience it would be impossible to correctly put together the methodology. The procedure, in the sense of technical norms is, and will be ever more, put together and defined by technical personnel but what is perhaps lacking is guidelines about what to in fact measure, or rather, looking at a painting in the usual way, which points or areas need to be taken into account for its memorisation for the future. Put simply, what and in what way it would be useful to record. Clearly the question, when looked at in its entirety, is extremely complex, given that, for example, it should not neglect the aspect of the materials used in the point measured - with one pigment deteriorating differently from another and so on – but nevertheless, even if the artist conceived the work in question in terms of "non-immobility of materials", the memorisation of the starting point is important, at the very least as documentation.

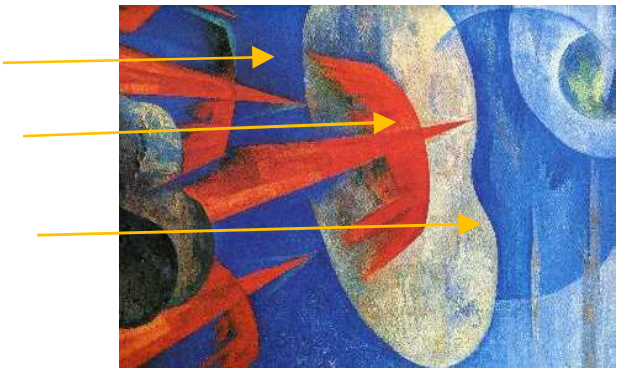

Figure 4. Measurement points. Each point is an area and the measure is the media of ten spots – Baldessarri, aeropittura, 1934

4. Restoration and cleaning

Colorimetry can have only an auxiliary role in restorations or cleaning. In such cases it is important to keep to the spectral reference factor (SRF) which is more related to the material used in the point measured. For every visible wavelength an SRF graph represents how much of it gets reflected in the point measured. During cleaning one can, comparing before and after but this is rather random, even try to extract "the colour of the dirt".

The following example is a significant one. Figure 5 shows colour measurements during the Pala di Pesaro (Savoldo 1524) restoration. It is possible to observe differences between before and after cleaning (blue points) and to do a comparison between the trends in reflectance factor in three different areas in a painting. Assuming that the "dirt" is uniform, the result is a yellowish colour as expected. This is the reason why graphs of before and after show limited differences as regards flesh tones and show the appearance of the curve of the blue of the sky and even more the violet of the robe, which has become brown.

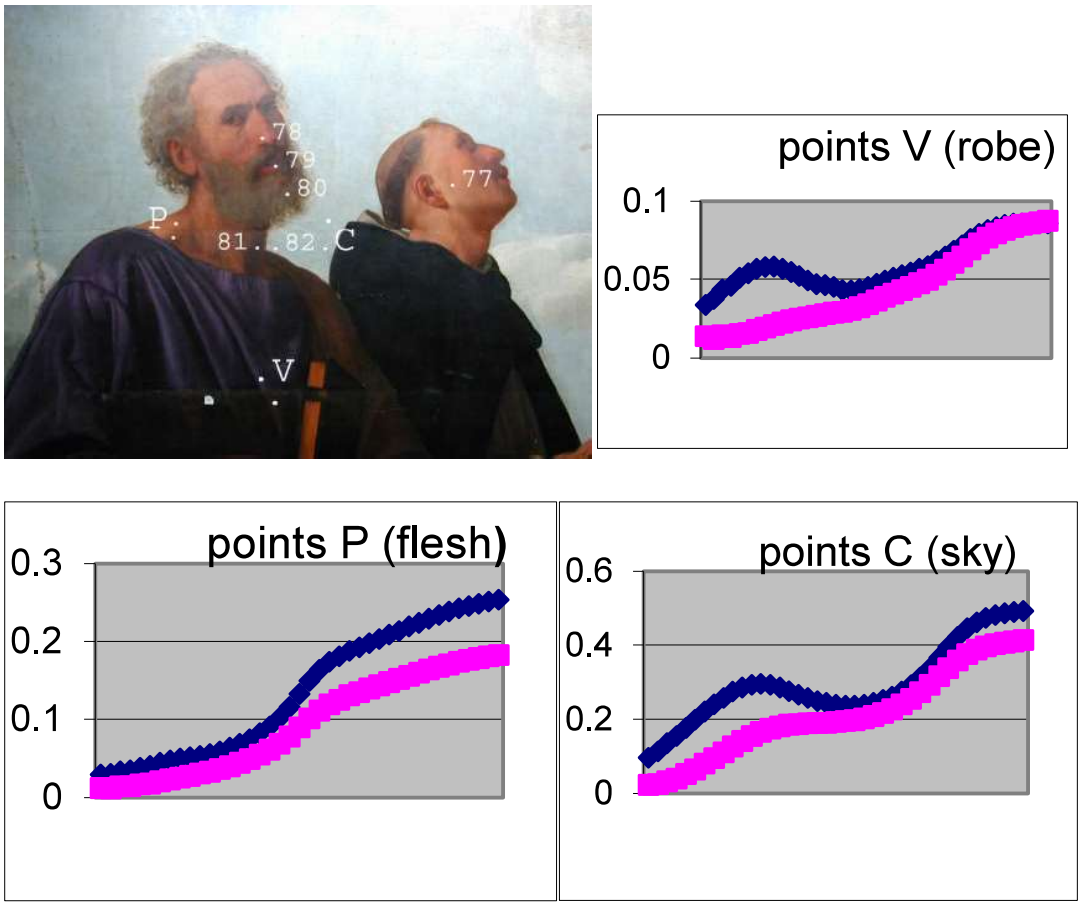

Figure 5. Pala di Pesaro (part.). Savoldo 1524. Color measurements before and after the cleaning. Spectral reflectance factor (SRF) versus λ (wavelength). blue = cleaned

In any case during cleaning, especially if conducted by several persons, it can be useful to have objective measurements of a layer of paint that is being cleaned in areas that are of reasonably the same colour (Fig 6.) or classify and link parts of a painting that needs to be put back together again especially in the case of decontextualized fragments (Fig 7).

Figure 6. Guido Reni – Trinity - 1625
Particular during the cleaning

Figure 7. Rebuilding after the earthquake. Colorimetric photographs were made of fragments of the frescos in Assisi while they put back together.

5. Monitoring for conservation purposes

A very important principle results in the analysis of colour formation physical processes:
A material, reflecting visible electromagnetic waves, can vary while its colour stays the same and this is through metameric effects, but if its colour varies, there has certainly been a variation in the material, given that light gets reflected differently.

The statement "The material may change and the colour remain the same but if the colour changes the material has changed" is applicable here.
This gets translated into a simple checking concept if a work of art is getting altered. As an aim of conservation monitoring we therefore mean the periodical measurement of colour in the very same places. Clearly, this is a so-called first level analysis, that is a simple alarm signal that a material is changing but without indications as to the causes of such a change. It is then the task of whoever is in charge of safeguarding a work to evaluate the need for other analyses to identify the causes of this variation.
Obviously, as we already said when talking about measurements with the aim of communicating information about the original colour of a work to the future, the choice of the points involved and their precise identification are important, but here another aspect arises, that is the choice of an appropriate interval in time between one monitoring campaign and another, given that "natural" degradation is different between a Roman fresco and a watercolour. Of course such a choice will be up to the operators and can be modified in line with the trends in the variations found during the monitoring campaigns. All this, of course, in order to get an alarm call before a variation can be seen by the human eye and its memory, and thus when already too late.
One of the first example of this kind of monitoring was the roman Villa di Arianna. (Fig. 8 and 9)

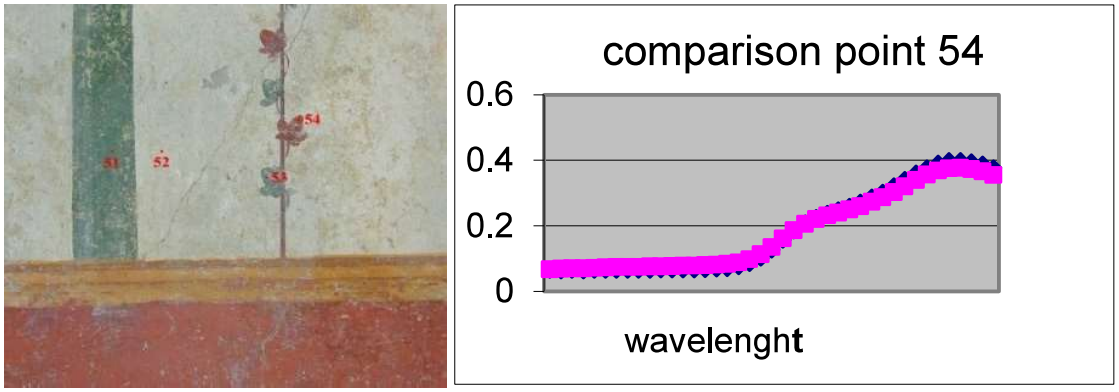

Figure 8. Spectral reflectance factor versus the wavelength in the visible region (380 – 780 nm.) Comparison of two points in a fresco of the Villa di Arianna. The blue line represents the measure after 6 years. No difference. On the contrary there is a big difference in the following figure 9.

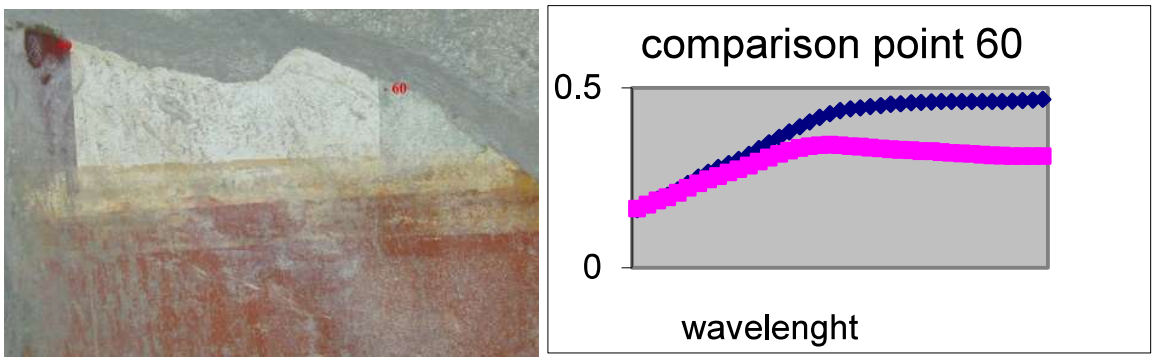

Figure 9. Comparison of measurement points of a Villa di Arianna fresco.

6. Procedures and new possible avenues

Procedures:

A defined protocol does not exist but only some recommendations regarding: **data memorization, identification of the point measured**, **experimental conditions** and **instrument parameters**.

The most significant problems are those regarding the choice of the diameter of the measurement spot, the uniformity of the colour in the area being measured and if it possible to conduct contact measurements (even if very light ones).

There are normally three types: an area with a uniform colour, a point-like area and a variegated area like, for example, some wood with slight veining. In the first case one only needs to collate some reliable data and, of course, it is easier with a spectrophotocolorimeter with a large diameter spot. Point-like measurements need a small diameter spot and the recommended procedure is to repeat the measurements several times but always by moving the instrument away and repositioning it. A variegated or non-uniform area requires a statistical approach, that is defining within an area an even relatively large section, like a square with sides of several cm., taking a large number of measurements within the square and using the average of them.

The relative protocols have not been finalised yet but what is important is that every measurement be clearly memorised in all its aspects and not clearly only to the measurer. Consequently not only the specification of the measurement spot and of the result, but also the auxiliary data like instrument used, number of measurements used to obtain the average, spot diameter, etc. Only in this way will operators, carrying out subsequent measurements or at least needing to interpret the data, be able to take the right actions to get a correct comparison.

As regards monitoring for conservation purposes certain criteria and recommendations should be considered:

10 % of the measurements should be repeated during the same campaign by another operator in order to verify the data's repeatability and the **ΔE** should be calculated. The **ΔE** is the colour difference between two points in the same colorimetric reference space (CIE Lab) and is none other than the geometric distance between two points in this space, the axes of which are L*, a*, b*. This value implicitly involves the reliability of the data.
In the case of conservation monitoring **2ΔE** is the alarm value.

New possible avenues:
The graph of the SRF as a function of the incident radiation (λ) wavelength is the most significant piece of data for interpreting a material. A comparison between the graphs of two points can only suggest if the colours are the same but comparisons are now being made that seem more significant when observing the derivatives of these graphs. There is no correct and comprehensive physical interpretation but in the majority of cases things seem to add up.
Let's now observe some results of the Etruscan Tomb of the Reliefs in Cerveteri.
The painted plasters were subdivided into 6 red zones and in 3 yellow zones in order to carry out the usual measurements. The red zones data were compared with the data of a red plot of red ochre musealized and found during an excavation.

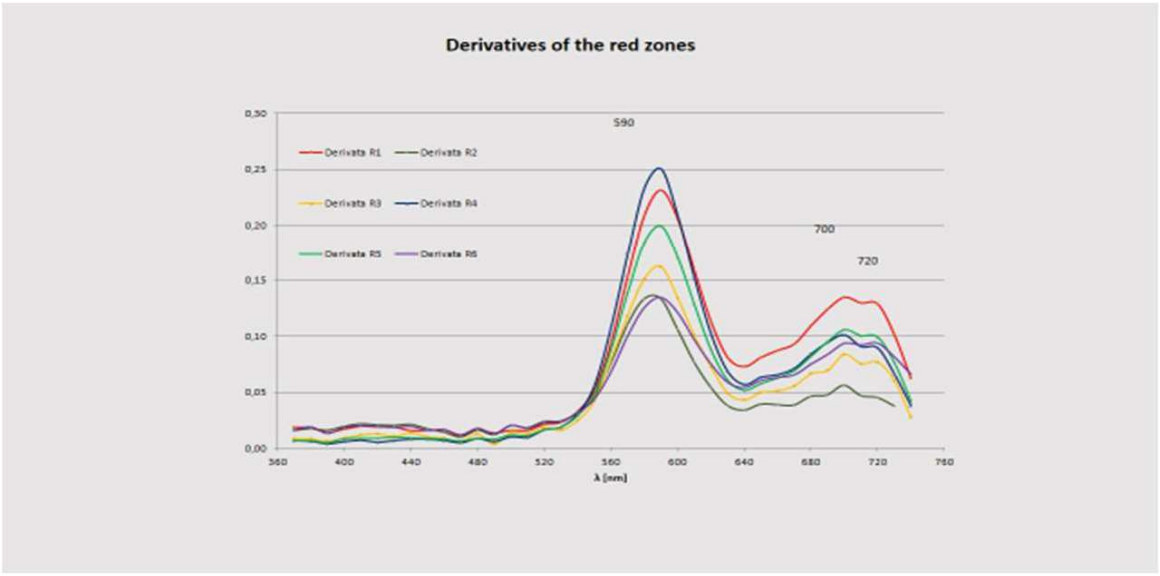

Figure 10.

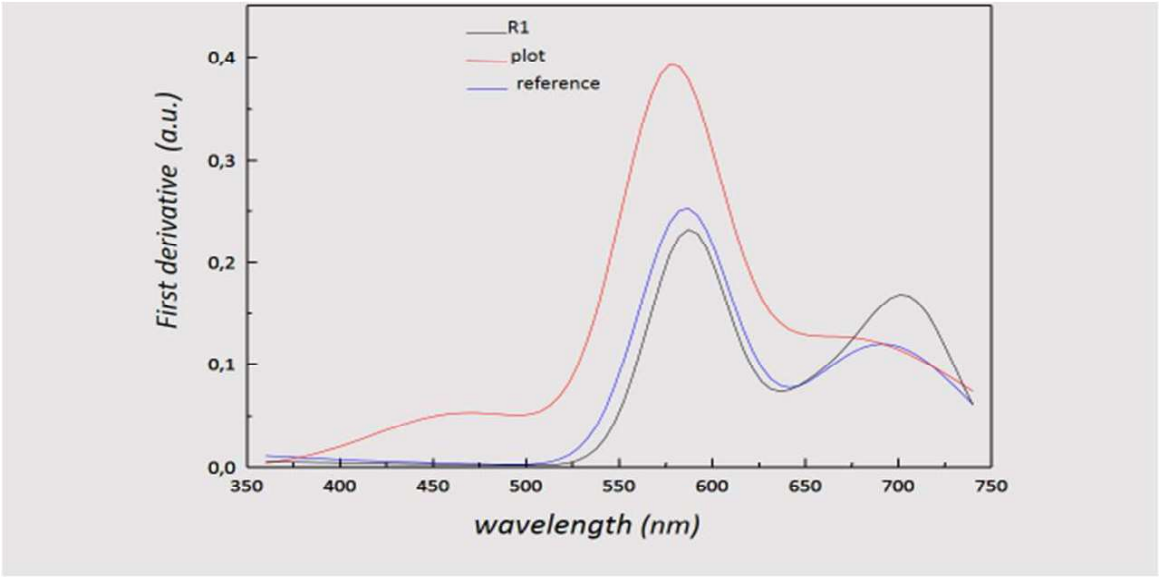

Figure 11.

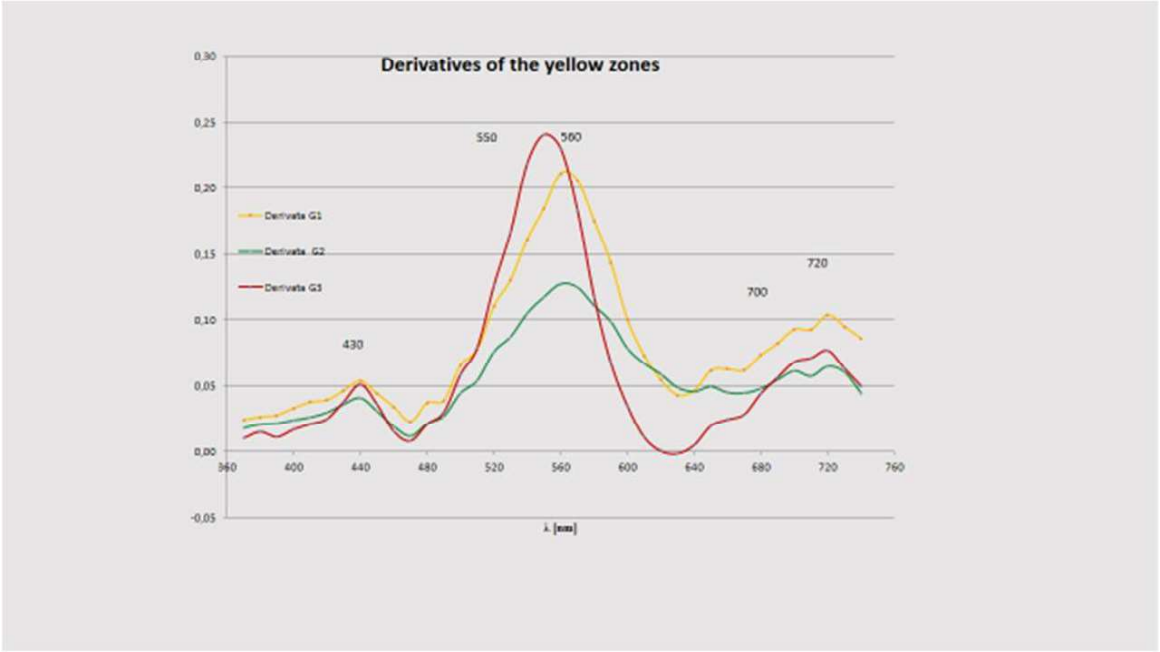

Figure 12.

The graphs of the derivative of the red zones (Fig.10) may confirm that the material is the some especially if we look the Fig.11 that represents a comparison with the red plot and with reference material. On the contrary the derivative of the yellow zones (Fig.12) shows high probability of quite different material.

7. Conflict of interest declaration

The author declare no conflict of interest.

8. Funding source declaration

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10. Short biography of the author

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References

Cennino Cennini "Il libro dell'arte" a cura di Fabio Frezzato – Neri Pozza Ed., Vicenza 2004 ISBN 88-7305-910-4

C. S. Plinio " Naturalis Historia" - Giulio Einaudi Ed., Torino 1988 ISBN 88 06-11420-4

Vitruvio "De Architectura" - Giulio Einaudi Ed., Torino 1997 ISBN 88-06-12239-8

"La fabbrica dei colori" – ed. Il Bagatto, Roma 1986 ISBN 88-7755-0503

Claudio Seccaroni "Giallorino" – De Luca Editori, Roma 2006 ISBN 88-8016-687-5

Anna Cocchiararo, Sergio Omarini "Indagini storiche e colorimetriche sul pigmento Giallo di Napoli" - C.E.T. Firenze 2006 ISMN 88-7957-252-0

Ernesto De Carolis "Rosso Pompeiano" – Electa, Milano 2007 ISBN 978-88-370-5933-0

Sergio Omarini et al. "Analisi colorimetriche di pitture murali nella necropolis di Cerveteri" – Morrone ed., Siracusa 2008 ISBN 978-88-95936-11-6

Sergio Omarini "The use of Spectrophotocolorimetry techniques in modern art" - Proceedings of European Cultural Heritage Preservation, Bozen 2013

Claudio Oleari "Misurare il colore" – Hoepli, Milano 2012 ISBN 978-88-203-4126-8

Mark Fox "Optical properties of solids" Oxford University Press, Oxford 2003 ISBN 0-19-850612-0