Light and colors in the “Villa dei Misteri”

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ABSTRACT

When dealing with cultural heritage, lighting design becomes really thorny, due to the necessity to keep the balance between artworks valorization and conservation requirements. Lighting characteristics have a significant impact on artworks fruition and obviously on the related chromatic perception. An aware design necessarily needs preliminary scrupulous analyses of the pieces of art to light, aiming at defining its chromatic characteristics and at understanding the way it interacts with light. Given these premises, the paper shows a methodology used to characterize artworks colors, based on on-field measurements. The method was applied to a very interesting case-study: the ancient roman wall-paintings located in the triclinium of the villa of the Mysteries in Pompeii. The study was divided in two parts: the analysis of the current lighting conditions and the chromatic analysis of wall-paintings colors. The former part reports results of illuminance, irradiance and luminance measurements, describing daylighting conditions inside the villa. The latter focuses on chromatic properties of the wall-paintings pigments. Predominant colors were identified and for each one of them an analysis area was chosen. Spectral reflectance measurements were performed for different points belonging to each chromatic area and the related CIELAB color space chromatic coordinates were calculated and compared.

KEYWORDS

Villa of the Mysteries; Roman wall-paintings colors; Archaeological heritage lighting; Daylight;

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1. INTRODUCTION

Colors perception depends on many factors, some attributable to sources used to light the observed objects and others to the optical properties of the objects themselves and of the space they are located in. Moreover, it cannot be neglected that, as for all visual phenomena, color perception is also influenced by observer's psychological and physiological conditions.
Although the enhancement of colors perception is essential in all lighting designs, it obviously becomes crucial in cultural heritage applications (Chen et al. 2016; Csuti et al. 2015; Nascimento and Masuda, 2014; Pridmore, 2017; Schanda et al. 2015; Yoshizawa et al. 2012; Zhai et al. 2015; Zhai et al. 2016). In these cases, it is fundamental to define a proper balance between the necessity to highlight chromatic properties of lit artworks and to protect them by the light-connected damages, fulfilling prescriptions about maximum exposure levels (CIE - Commission Internationale de l'Eclairage, 2004). The complexity of lighting design is greater when artworks are not located in museums or exhibition rooms, but are positioned in their original place and the entire architectural space must be considered a piece of art, e.g. churches or archaeological ruins. In these cases, design problems are greater: the location of luminaires is difficult because their installation must not adulterate the integrity of the cultural good; moreover, often it is not possible to access to all architectural spaces and consequently it must be considered that the artwork to lit (e.g. a wall-painting or a mosaic) will be observed from a specific distance and that its details will not be entirely appreciated by the observers.
In order to account for all these aspects, when lighting design deals with cultural heritage the preliminary analyses are crucial.
Given these premises, the goal of this paper is to present a methodology useful to scientifically characterize artworks colors, in order to obtain information useful for the electric light design. Specifically, it aims on one hand at evaluating architectural surfaces properties from a photometric and colorimetric point of view and, on the other hand, at describing the way light and space interact. This methodology was used during the preliminary studies to define the lighting system for some of the most famous ancient roman wall-paintings: the wall-paintings of the triclinium of the villa of the Mysteries in Pompeii. Moreover, the analysis focused on the wall in front of the entrance of the *triclinium*.
The study was divided in two parts: the analysis of the current lighting conditions and the chromatic analysis of the wall-painting colors. Daylight irradiance measurements and luminance maps were obtained to characterize the luminous environment. Then, the wall-painting was divided in several chromatic areas based on its predominant colors. Each area was characterized by means of spectral reflectance factors measurements and the chromatic coordinates of the measured samples were calculated and compared.

2. ROOM OF THE MYSTERIES DESCRIPTION

Villa of the Mysteries is an amazing example of suburban roman villa. It was partially discovered in 1909-1910 and completely revealed in 1929-1930 by Amedeo Maiuri. It probably belonged to Istacidii, one of the most influential roman families during the Augustan age. Its present layout derives from renovation works, which began after 62 A.D. earthquakes and aimed at converting the building from *"villa di otium"* into a sort of farm used to wine production.
Built on the slope towards the seaside in the 2nd cent. B.C., it was renovated around 60 B.C., then again in the 1st cent. A.D.: it is one of the more than 100 villas discovered in the Vesuvian area, usually related to agriculture, but it was also fashionable for the upper classes to have an out of town *"getaway"* where they could recreate an environment suffused with Greek culture. It includes a residential section overlooking the sea and decorated with splendid specimens

Figure 1 - The wall-paintings of the triclinium

of *‘second style’* (early 1st cent.-20 BC), and a servants’ section next to the winery rooms (*torcularia*): here stands a rebuilt grape press, with its ram’s head trunk. Along the walls of the triclinium there is the large wall-painting (*megalographia*) representing a mystery ritual scene (whence the name of the villa), a woman’s initiation to marriage (see Figure 1). Splendid examples of ‘*third style’* on a black background are found in the tablinum, with miniaturist motifs drawn from Egyptian art (Brendel, 1966; Burkert, 1989; Maiuri, 1931; Pugliese Carratelli, 1990; Torelli, 1984).

As it was mentioned in the introduction, the paper focuses on the analysis of the triclinium and specifically on the wall-painting belonging to the wall 1 (see Figure 1).

The triclinium, also called room of the Mysteries, is about 5m*7m wide and 5m high. The optical and chromatic coordinates of the wall-paintings are described in the following paragraphs. As for the other surfaces, the ceiling is covered by a plaster (reflectance factor equal about to 0.3) and the floor is composed of two different marble squared tiles, arranged to define a geometrical pattern. Tiles are light and dark grey (reflectance factor equal to about 0.49 and 0.11 respectively).

Daylight enters the room through a large door located in the wall 4 and a window belonging to the wall 3. Specifically, the door faces a lateral passage, coming from the exedra and daylit by a large window (see villa plan in Figure 2). A little amount of daylight enters this passage also through its east wall, that is partially collapsed. On the other hand, wall 3 window faces the exterior colonnade. Both the windows (that of the room and that of the lateral passage) are equipped with recent shading devices composed of vertical movable wooden slats.

Nowadays the visitors’ access to the room is forbidden to preserve the original marble floor and people can look at the wall-paintings only from the door limit. Given that, considering the possible points of view toward the murals, veiling effects occur on wall 1, due to the light entering through the passage window. So, the corresponding shading device should be completely closed to avoid them.

3. METHOD

The analysis of the environment is divided in two parts: analysis of current lighting conditions and analysis of the chromatic coordinates of the wall-painting belonging to the wall 1.

3.1. ANALYSIS OF CURRENT LIGHTING CONDITIONS

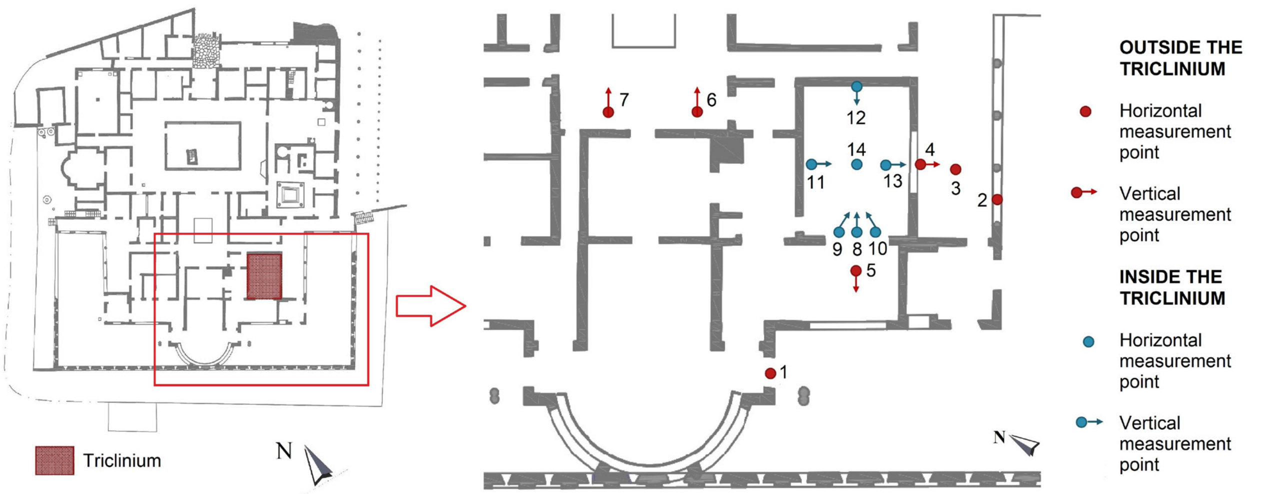
At present, the only source used to light the room of the Mysteries is daylight.

Daylight measurements were performed to have an idea of the indoor luminous environment and to investigate the interaction between light and surfaces. Measurements were performed during a February sunny morning at about 10 a.m.

Thanks to the use of a Konica Minolta CL500A spectroradiometer, spectral irradiances were measured in several points inside and outside the triclinium. Starting from spectral measurements the corresponding illuminances and Correlated Color Temperatures (CCTs) were derived and analyzed. Illuminances give the idea of the quantity of the light entering different spaces, whereas CCT values informs about its quality in terms of tonality (warm light when CCT is lower than 3500 K, intermediate light when CCT ranges from 3500 and 5500, cool light when CCT is higher than 5500 K).

In Figure 2 measurement points locations are reported: circles correspond to the horizontal measurements and circles provided with the arrows are related to the vertical ones. In the former case the instrument was positioned on the floor, in the latter the arrow direction corresponds to the view one and the spectroradiometer was

Figure 2 - Villa plan and location of measurement points



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located at a distance from the floor equal to that of the eyes of a medium height standing observer. During measurements the shading devices of the passage window were completely closed.

As it can be inferred from the image, daylight was measured not only in the triclinium but also inside the exedra (point 1), the atrium (points 6 and 7), the colonnade (points 2,3 and 4) and the passage from the exedra (point 5), to underline the variety of lighting conditions occurring in the different villa spaces. This allows to underline the capability of architectural surfaces in modifying light characteristics. Reflecting and absorbing light, they modify incident light spectra affecting also their intensity and quality.

Moreover, luminance maps related to the wall-painting of wall 1 were measured by means of a video-luminance-meter. The instrument is not a commercially available one, but it was developed at the Department of Industrial Engineering of the University of Naples "Federico II" (Bellia et al. 2002; Bellia et al. 2003). It is composed of a hardware part (a digital reflex camera Canon EOS 20D equipped with a photopic filter) and a software (a Matlab-based calculation tool). Specifically the software derives luminance maps starting from three photos taken with different shutter times (2 s, 1/15 s and 1/500 s), necessary to obtain information about low, medium and high luminance ranges. Considering that the luminance levels of the wall 1 during the survey was really low, the obtained luminance maps were processed in order to infer two images, the first one representing only areas in the range between 0 and 3 cd/m2 and the second one reporting the areas between 3 and 6 cd/m^2.

3.2 ANALYSIS OF CHROMATIC CHARACTERISTICS OF THE WALL-PAINTING BELONGING TO THE WALL 1

The goal of the chromatic analysis is to describe the colors of the selected painting. For this purpose, it was chosen to use the CIELAB chromatic space coordinates.

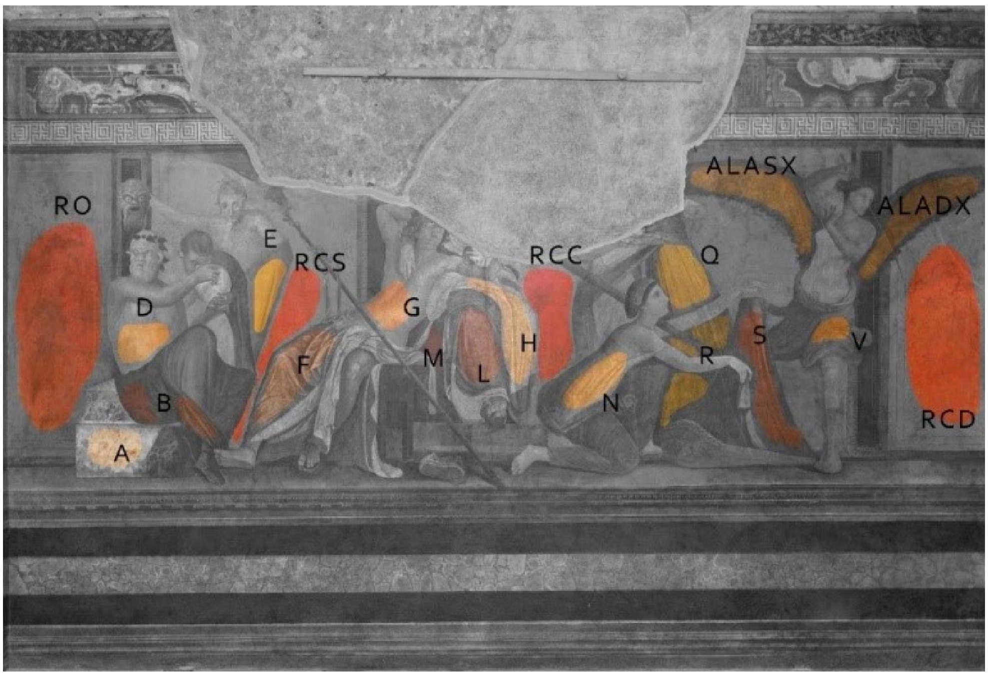
The painting was divided in different chromatic zones and for each zone spectral reflectance measurements were performed. The CIELAB coordinates were then calculated starting from spectral reflectance factors data.

Wall 1 wall-painting pictorial composition is complex and many colors are used to define figures bodies, their dresses, objects and the decorative elements such as the background and the frames. Considering the distance of the wall from the observer, it looks like the represented figures are composed of well-defined chromatic areas, each one characterized by a dominant color. However, at a smaller distance it is possible to notice that each one of these chromatic areas is composed of different colored brush strokes and that perceived colors are defined by the interaction of several pigments. In order to define wall-painting colors, 28 different areas were identified as reported in Figure 3.

For example, the areas identified by D and G letters correspond to figures bodies and are characterized by two different tones of flesh-color. The areas indicated as RO, RCS, RCC and RCD are all red.

For each one of the reported areas, several measurement points were chosen and the corresponding spectral reflectance factors were measured by means of a Konica Minolta CM 2600d spectrophotometer. For example, considering RO area, 20 different samples were analyzed, whereas 13 points were considered in

Figure 3 - Analyzed chromatic areas



L area case. The number of selected samples was chosen depending on the size of the chromatic area. For each sample the corresponding total reflectance factor was derived considering the standard D65 illuminant, the standard A illuminant and the on-field measured spectrum incident on the wall-painting (see Graphs 1-3). Then the average total reflectance factor related to each chromatic area and the dominant wavelength were evaluated. Moreover, starting from the spectral reflectance factors, by applying proper calculation models, the chromatic coordinates in CIELAB color space were derived for each one of the defined samples. Then the average chromatic coordinates L* (Lightness), H* (Hue) and C* (Chroma) were defined to obtain a "reference mean color", representative of each chromatic area. The arithmetic mean can be used in this case, because the chromatic samples are similar and, considering the observation distance, each area is perceived as painted in a unique color. The related standard deviations were calculated to evaluate if, for each area, the reference mean color can be considered representative of the measured samples. Finally, the differences between the chromatic coordinates (L*, H* and C*) of each sample and those of the reference mean color were evaluated and results discussed.

4. RESULTS

4.1. ANALYSIS OF CURRENT LIGHTING CONDITIONS

Table 1 reports measured illuminances referred to each measurement point. As it can be inferred by the table, the order of magnitude of illuminance values remarkably changes depending on the point location. In the exedra (Point 1) illuminance is greater than 60000 lx and it is very high also in the colonnade (Point 2), where it substantially decreases on the decreasing of the distance from the triclinium wall.

As for interior points, values are similar both in the atrium and the triclinium and generally lower than 100 lx. Specifically, minimum values are measured at the eyes height of a generic observer looking at wall-paintings, standing at the door limit (Points 8, 9 and 10). On the contrary, the highest ones are measured at the floor (Point 14), that receives the light directly entering through the window, and at Point 13, receiving the light coming from the window.

Considering adaptation time of human visual system, coming from the exedra and arriving to the triclinium, the sudden fall in illuminances makes the visitor perceive the room of the Mysteries as really dark.

Depending on the environment characteristics, daylight significantly changes in terms of spectral power distribution as well. Graphs 1-3 report measured spectral irradiances corresponding to the 14 points.

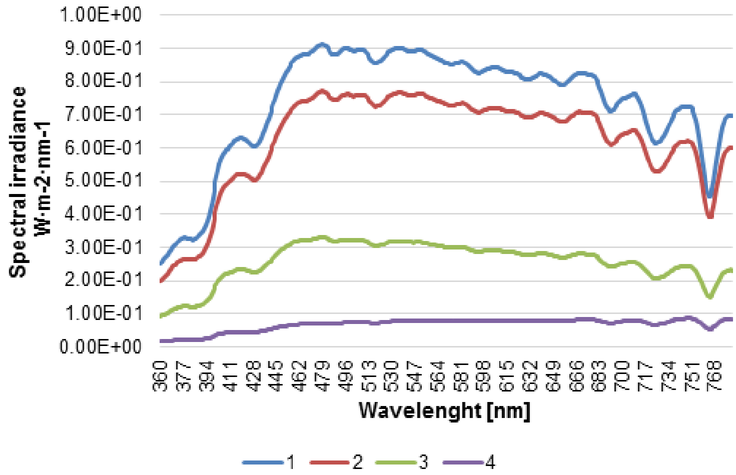
As for points that directly receive daylight and for which environment surfaces reflections incidence is low (1, 2, 3, 4, 13 and 14), the spectrum trend is similar to that of a standard D65 illuminant. As for atrium points (6 and 7), their spectra are characterized by high values corresponding to wavelengths from 400 nm to 500 nm. Then, they have a decreasing trend on wavelength increasing. This is probably due to the fact that the atrium is daylit by the impluvium: Given the moment of the day (about 10 a.m.) when the measurements were performed, the light entering the space is substantially skylight and the solar disc is not in the sky region visible through the impluvium from measurement points. On the contrary, as regards the points inside the triclinium, except the 14 one, the spectrum trend is completely

Measurement point	Illuminance [lx]
1	63060
2	53759
3	22213
4	5673
5	21
6	69
7	93
8	33
9	43
10	26
11	90
12	58
13	254
14	333

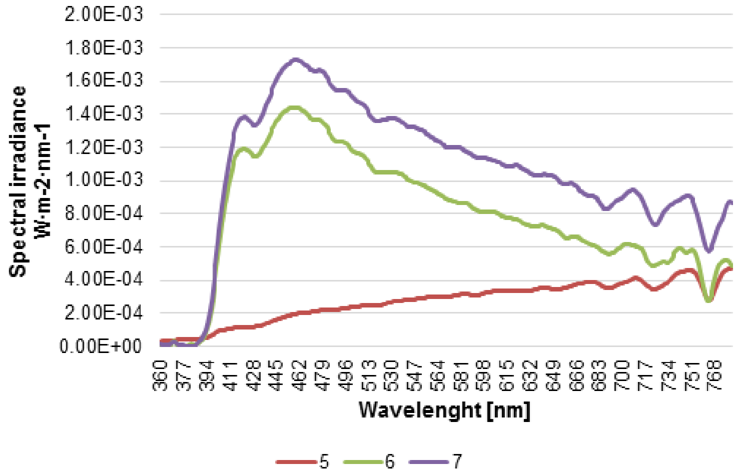
Measurement point	CCT [K]
1	5408
2	5339
3	5616
4	4742
5	3868
6	8719
7	7390
8	3511
9	3624
10	3859
11	4445
12	3478
13	4612
14	5389

Table 1 - (Left) Illuminances measured at the points 1-14

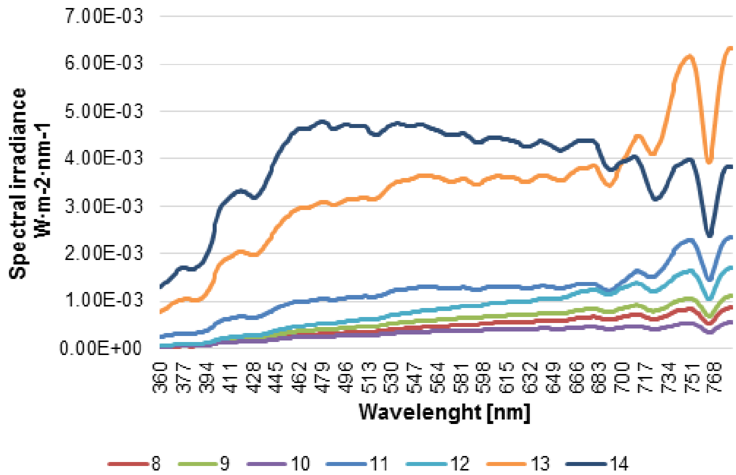
Table 2 - (Right) Correlated color temperatures referred to the measurement points



Graph 1 – Spectral irradiance measured at the points 1-4



Graph 2 - Spectral irradiance measured at the points 5-7



Graph 3 - Spectral irradiance measured at the points 8-14

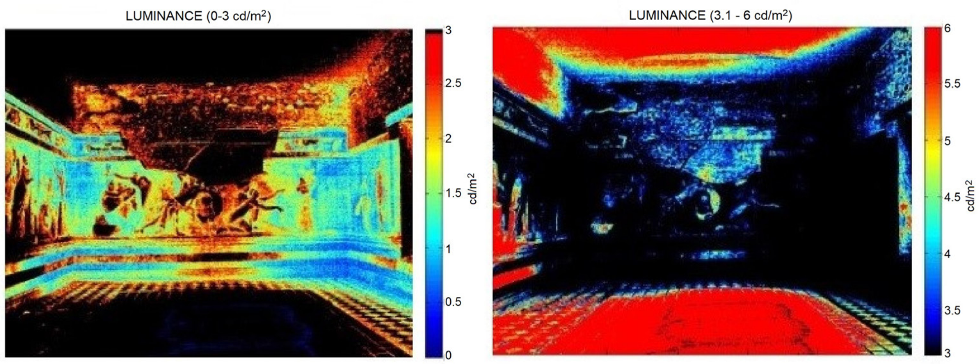


Figure 4 - Luminance maps referred to the wall 1

different and characterized by an increasing and almost linear trend till about 650 nm, with very small values corresponding to short wavelengths. After this 650 nm limit its trend is more irregular. This means that the environment has a great impact in modifying spectral daylight characteristics and, precisely, substantially absorbs short wavelengths radiations.

Consequently, CCT is extremely high at points 6 and 7 and greater than 5000 K for points outside the triclinium (see Table 2). Points inside the triclinium and at the limit of its door and window (4 and 5) are characterized by CCT comprised between 3500 K and 4500 K.

Figure 4 reports obtained luminance maps (range 0-3 cd/m^2 and range 3-6 cd/m^2).

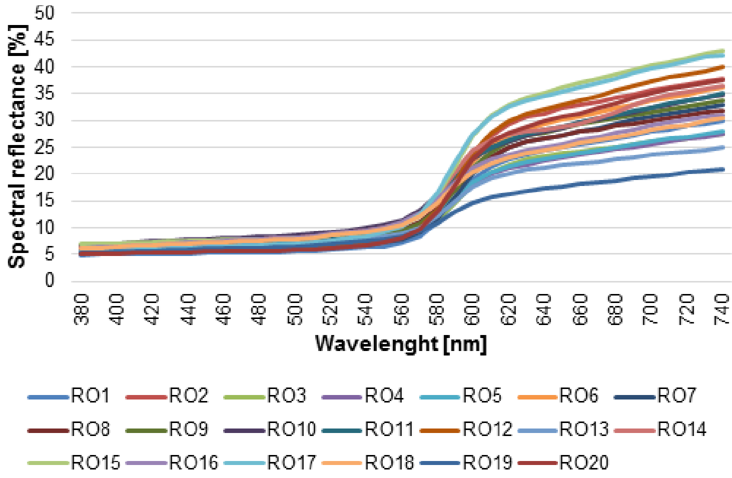
Most of the surfaces are in the range 0 – 3 cd/m^2 (scotopic/mesopic/photopic vision), whereas only small parts are in the range 3 – 6 cd/m^2. Consequently, the surface is characterized by small luminance values and luminance contrasts among the different areas are low as well. The perception of the different subjects represented on the wall-painting is then mainly due to chromatic contrasts rather than to luminance ones.

The results highlight several problems useful to lighting design. Illuminance measurements demonstrated that light levels vary a lot moving from a space of the villa to another. This can create visual adaptation problems, especially when the visitor arrives to a close space coming from another where the roof is collapsed. This is the very case of the triclinium as confirmed by luminance maps. Moreover, the comparison between daylight spectra in different points of the villa spaces revealed that the indoor surfaces particularly absorb low wavelengths radiations, reflecting the higher ones. This gives a warm tonality to the indoor lighting.

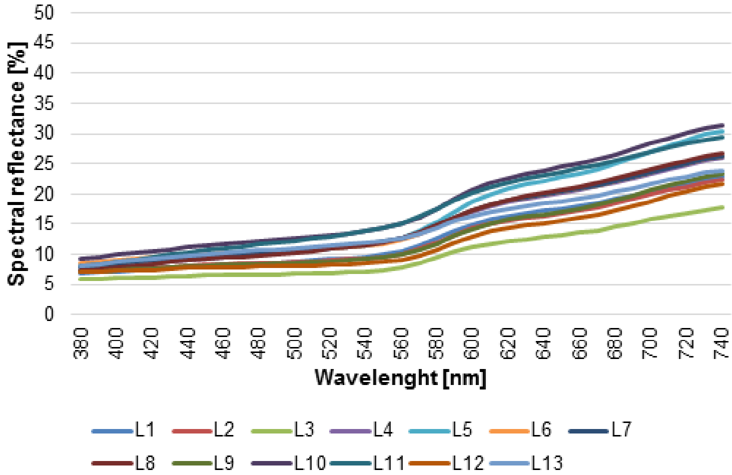
Despite the visual adaptation problems, the high light contrasts between the different spaces and

Chromatic area	ρ (A) [%]	ρ (D65) [%]	ρ (meas.) [%]	Dominant λ (A) [nm]	Dominant λ (D65) [nm]	Dominant λ (meas) [nm]
A	34	32	33	590	590	590
B	9	9	9	600	600	600
C	20	18	20	594	594	594
D	30	27	29	593	593	593
E	27	24	27	589	589	589
F	15	14	15	596	596	596
G	25	22	24	595	595	595
H	26	24	25	591	591	591
L	13	12	12	598	598	598
M	9	8	9	599	599	599
N	23	21	23	592	592	592
P	9	9	9	595	595	595
Q	19	17	18	589	589	589
R	13	12	13	587	587	587
S	10	10	10	602	602	602
T	16	15	16	601	601	601
U	12	11	11	595	595	595
V	17	15	17	595	595	595
Z	19	17	18	595	595	595
X	25	22	24	593	593	593
RO	14	11	13	603	603	603
RCS	17	13	16	606	606	606
RCC	15	12	14	607	607	607
RCD	18	14	17	605	605	605
VE	14	13	13	581	581	581
VB	15	15	15	546	546	546
ALA SX	14	14	14	590	590	590
ALA DX	11	10	10	592	592	592
MAXIMUM	34	32	33	607	607	607
MINIMUM	9	8	9	546	546	546

Table 3 - Average spectral reflectance factors and dominant λ referred to the considered chromatic areas



Graph 4 – Spectral reflectance factor referred to RO chromatic area



Graph 5 – Spectral reflectance factor referred to L chromatic area

the effect of architectural surfaces in modifying light characteristics surely contributes to enhance the emotional perception of the villa. Here, light plays a fundamental role, like in other mystic places such as gothic churches. Lighting design should enhance these aspects.

4.2. ANALYSIS OF CHROMATIC CHARACTERISTICS OF THE WALL-PAINTING BELONGING TO THE WALL 1

Spectral reflectance factors were measured for all the samples of the chromatic areas reported in Figure 3. For example, Graphs 4-5 report results referred to RO area characterized by a so-called Pompeiian red and to L area that is perceived as greyish-blue colored.

Even though the chromatic perception of the two areas is really different, all colors reflect longer wavelengths in the visible spectrum more and shorter wavelengths less. In the painting the L area appears as grayish-blue, compared to the other surrounding colors, but, as it can be inferred by Graph 5, spectra of the samples of the L area are similar to those of the RO area (perceived as red). This is a clear demonstration about the fact that colors perception is a complex mechanism and that the same pigment can be differently perceived if associated to other different colors. This is particularly clear if Figure 1 (where the painting is represented completely colored) is compared with Figure 3 (where analyzed areas were isolated on a grey-scale background).

Table 3 reports for each chromatic area the average total reflectance factor of all samples and the dominant wavelength. Irrespective of the considered illuminant, given a chromatic area, reflectance factor values are similar and always lower than 35%. The minimum reflectance factor measured is 8% related to M area and the most of values are lower than 20%. As for the Dominant λ, it is always comprised between 546 nm and 607 nm.

Graphs 6-7 report CIELAB coordinates for the samples belonging to the RO and the L area evaluated considering a D65 standard illuminant. It must be underlined that the colors of the graphs do not correspond to perceived colors, indeed, both groups of samples are in the red-yellow area of the diagram and characterized by law Chroma values.

For each chromatic area, a reference mean color is obtained by evaluating the average values of L*, H* and C*. Table 4 reports obtained results for 9 different areas and together with related standard deviations. Moreover, differences between L*, H* and C* values related to each measured sample and the reference mean color were calculated. Minimum and maximum

Chromatic area	Chromatic coordinate	Average value	Standard deviation	Minimum value of the difference	Maximum value of the difference
E - yellow area	L*	58	2	-4	2
	H	73	2	-3	1
	C	38	4	-8	4
A - white area	L*	64	4	-6	4
	H	73	3	-6	4
	C	21	5	-7	11
D - pink area	L*	60	2	-2	3
	H	64	3	-2	5
	C	32	2	-2	3
L - blue area	L*	42	3	-7	5
	H	47	6	-9	10
	C	14	2	-2	3
R - dark green area	L*	42	2	-4	3
	H	84	4	-7	6
	C	17	4	-5	5
RO - red area	L*	41	2	-3	4
	H	38	2	-2	4
	C	30	4	-6	8
ALADX - green area	L*	39	3	-4	8
	H	65	4	-6	7
	C	13	2	-3	4
B - violet area	L*	37	1	-2	2
	H	41	5	-5	10
	C	12	1	-2	3
M - dark blue area	L*	37	1	-2	2
	H	42	6	-5	10
	C	10	1	-1	2

Table 4 - Average values and standard deviations of chromatic coordinates related to E, A, D, L, R, RO, ALADX, B and M area

values are reported in the last two columns of the Table 4.

Generally standard deviations are low, consequently the reference mean color can be considered representative of all the measured samples. As it can be inferred by the table, the so-called Pompeiian red has a L* value equal to about 41, H* value equal to about 38 and the C* value equal to about 30. The colors perceived as violet and blue are characterized by very similar Hue value (about 40), which is very close to the red one. The lightness is about 38 and the Chroma is about 10 (slightly higher as for the violet).

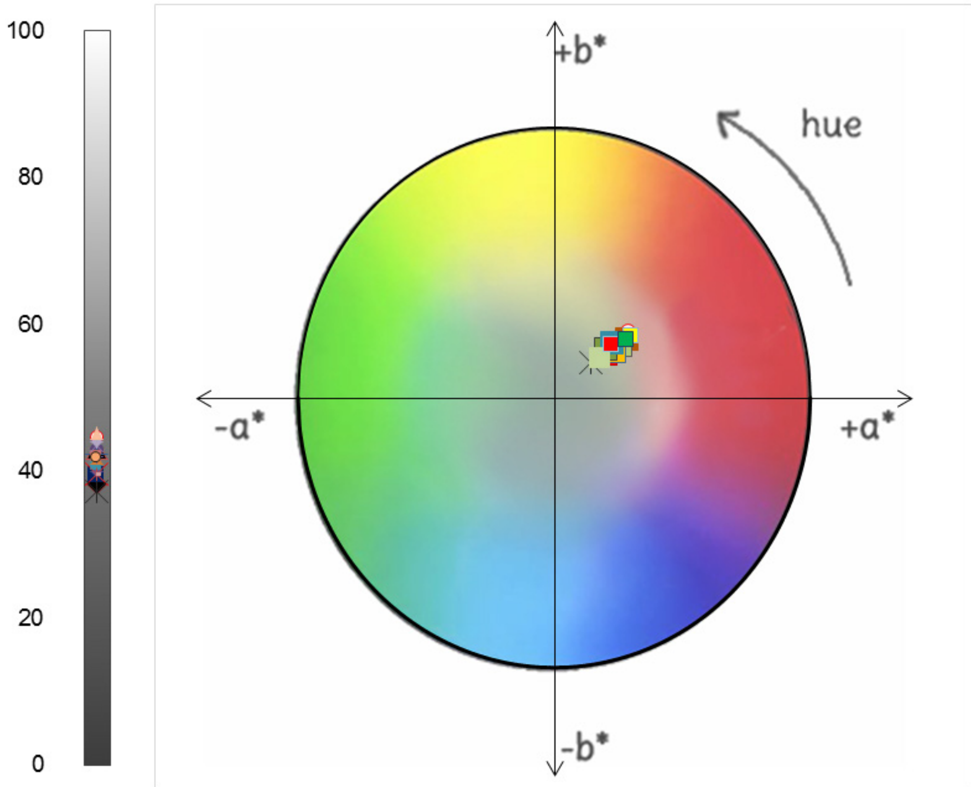
Depending on the chromatic area, the differences between the measured samples and the reference mean color can be more or less significant. For example, considering the D area, L*, H* and C* are characterized by similar and small oscillations. On the contrary, as for B and M areas, L* and C* variation ranges are very small and the H* is the more variable characteristic.

In conclusion, the analyses demonstrate that all the painting surfaces are characterized by low total reflectance factors and that higher spectral reflectance factors correspond to high wavelengths. Indeed all the colors are contained in the red-yellow quarter.

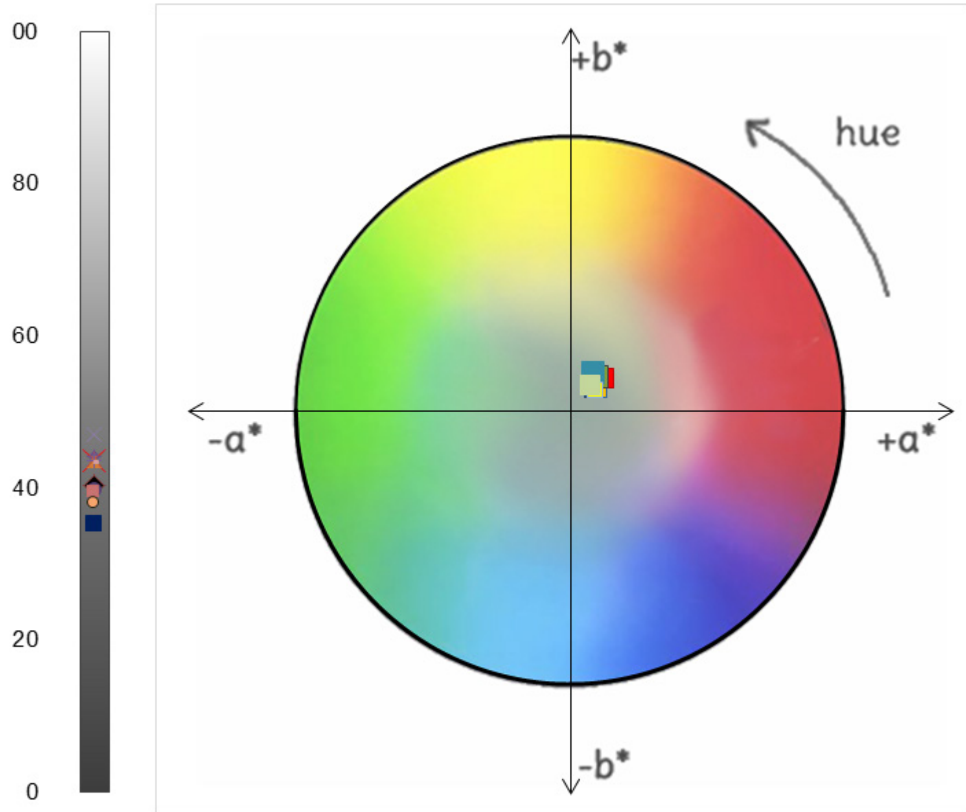
5. CONCLUSIONS

Paper presented preliminary analyses performed to define design criteria for the lighting system of the triclinium of the Villa of the Mysteries in Pompeii. Results demonstrated that in a typical sunny day, most of the surface is characterized by luminances in the range 0 – 3 cd/m^2. On the contrary, in the spaces outside the triclinium (the exedra, and the lateral passage), illuminance levels are high. Considering visual system adaptation time, this makes visitors perceive the triclinium as very dark. Indoor surfaces of the triclinium absorb short wavelengths of entering daylight and the measured CCT in different indoor points is comprised between 3500 K and 4500 K. Moreover, most of the wall-painting

Graph 6 - Chromatic coordinates in CIELAB space of samples belonging to RO area



Graph 7 - Chromatic coordinates in CIELAB space of samples belonging to RO area



measured colors are in the first quarter of the CIELAB diagram and characterized by law C* values. Even colors appearing blue, contain red and tend to the violet. So, despite the perceivable chromatic variations, the most of colors are warm and little saturated.

In summary, the lighting conditions appear scarce and not adequate to guarantee pleasant visual and chromatic perception. Considering that the group of the wall-paintings of the triclinium is one of the most important in Pompeii and it is publicized as one of the symbols of the archaeological site, major attention should be given to enhance visitors' experience. People are likely to have great expectations regarding this piece of art. Probably, this space should be the end of the visit path and should be perceived as a space properly luminous and brilliant in colors.

Considering that daylight entering the triclinium is not sufficient and that the shading devices cannot be open to avoid disturbing veiling effects, the use of electric light would be beneficial even during day. Illuminance levels higher than current ones would allow to better appreciate painting details. Considering that light levels must not be excessive to avoid light-connected damages, it would be useful to install presence sensors, in order to turn on electric light only when necessary, i.e. when visitors are present. Considering the optical characteristics of the architectural surfaces, the choice of the light spectrum can be crucial. For example a cool light would make colors appear less saturated, on the contrary a warm light with a spectrum characterized by high wavelengths would enhance all colors of the paintings making them more brilliant.

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CONFLICT OF INTEREST

The author disclose any actual or potential conflicts of interest including financial, personal or other relationship with other people or organizations within three years of beginning the submitted work that could inappropriately influence, or be perceived to influence, her work.

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