Light, Information and Perception inside Historical Buildings. A Case Study

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Light, Information and Perception inside Historical Buildings. A Case Study.

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Abstract. Many literature studies demonstrated that technologies belonging to cognitive neuroscience can be used in museums. Physics, optics, thermodynamics and neurosciences applications can provide an important support to applied and practical research for lighting our Cultural Heritage. In our research we provided a multidisciplinary integrated approach for the study of the luminous climate inside a historical building: Villa La Quiete in Florence is the case study. The quantitative measurements of the relationship between observer and artworks were performed, with eye-tracking technique application. The Information Theory, read on a thermodynamic basis, the ergonomy of the multi-perceptive learning and optical physics, were the fundamental tools for the assessment of the correct light sources in terms of spectral emission and colour light temperature. The eye-tracking technique combined with the results of lighting parameter quantification, allowed checking how the colour of light changes the observer's perception, and from the information theory point of view, the communication and interpretation process of the signals due to different lighting. At the same time, it was also possible to measure by assessing the perceptive data of the visual path, and thus the neg-entropy, the informative content of the interaction of light with works of art.

Keywords: Lighting, Eye-tracking, Perception, Information, thermodynamics, LED

1. Introduction

The Sciences of the Cultural Heritage have oriented many studies to the relationship between observer and work of art, the latter meant in the broad sense (space, building, object of historical artistic value, etc). The measure of this relationship can be made with the eye-tracking technique and therefore aimed at a project based on forms of fruition and enhancement that will be convincing, effective and sustainable [1,2,3]. It is well known that the interaction between observer and object is a complex system of *top-down* cognitive processes (guided by knowledge, empirical, tactile, visual and previous kinesthetic experiences, semantic/cognitive representations and syntactic representations of the subject), and *bottom up* (guided by the optical, photometric, colorimetric properties of the object, but above all by light, luminance, spectral distribution and colour that invest it in the "perceptive neutrality" of the subject; [3,4]). Most of the literature concerns eye-tracking applications for ophthalmology, psychology, commercial research, medicine and psychiatry [5,6]. It is also used for people suffering from serious diseases or neurodegenerative diseases, because it allows communication only with ocular movements.

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Lately the eye tracker is also used for tool usability: e.g. to evaluate how and how much a website is visited [7,8,9].

The aim of our present research is to investigate the physical connection between light, perception and information/communication by an experimental methodological approach. The method here proposed can be a useful tool for lighting design oriented to light control and quality rather than quantity.

Our study starts from the strong belief that any efficient and effective lighting design, especially within historic buildings and museums, requires knowledge of light and its connected physical, optical, colorimetric, photometric and radiometric aspects. As a matter of fact, some recent studies concern the assessment of visual appreciation of light sources and LED in museum environment. In particular, the colour appearance and colour quality have been studied under different light sources and LED lighting settings [10,11,12]. Different approaches, based on Shannon entropy, have been proposed to study light and visual perception [13,14,15]. A "visual entropy" method combined with eye-tracker and spectral emission of light sources measurements has been used to assess the order of fixation transitions of driving-related eye-movements [13]. Others authors have provided a method for choosing informative lighting directions for physical objects through Shannon entropy [14]. Krejtz et al. [15] have suggested a method for quantifying eye movement transitions between different AOIs of works of art, using Shannon entropy for the calculation of stationary and transitional distribution of fixations.

Our present research aims at the application of eye-tracking technique for eye movement assessment (saccades and fixations), of an observers sample during the observation of frescoes in order to evaluate the influence of the different types of light on vision and perception. It was possible to verify how the interaction between light, information and perception, that constitutes the visual/perceptual experience of each subject can be modified by different light sources. Information Theory, on a thermodynamic basis (neg-entropy), the ergonomy of multi-perceptive learning and optical physics, were basilar for our proposed integrated approach. Eye-tracking measurements were the first step in testing visual material: fixations are necessary for gathering visual information and without them perception is impossible.

Following the approach suggested in [14,15] we could analyse results on perception and preferences of observers, patterns of their visual scanning, locally oriented viewing works of art under different LED sources, through entropy and then the information content of images. Combining these data analysis with photometric and colorimetric measurements, it was possible to choice the correct LED sources allowing the transmission of information content of the images (i.e. lower entropy production due to visual patterns and eye movements in different AOIs that is higher neg-entropy and for the observers higher attractiveness).

2. Material and Methods

2.1. Experimental set-up, measurement protocol and methodology

One of the two frescoed rooms, called "Boscherecce" and known as the “Rooms of the Lady” of Villa La Quiete, is our case study. In order to define the luminous climate of the room and consequently investigate the interaction between light and perception of works of art, the geometric relief and measurements of the architectural features were carried out. A laser distance meter DISTO D2- Leica Geosystem was used. This allowed us to derive the room-index necessary to obtain the total numbers of measurement points and the experimental grid dimensions referring to the method suggested by the UNI EN 12464-1 [16]: this index value is 0,77. The room is 6,80 meters wide and 8,90 meters long, with a height at the base of the vaulted ceiling of 4 m, 5,60 m at the highest point and 5,42 m at the intermediate point corresponding to the change in the vault curvature. The room has only one window which is always closed. During the experimental measuring campaign, the wooden entrance door was always kept closed to eliminate interference effects due to the light coming from the adjacent corridor. Only the presence of artificial light due to the antique chandelier in the centre of the ceiling, provided with 9 LED sources, was considered. In particular, these light sources are ZafiroLED with the following nominal data: 4W power, E14 connection, 470 lm of luminous flux emitted and 2700 K colour temperature. Information on thermo-physical properties of the existing materials were collected: this was possible by means of a thorough research combined with direct observations and a specific photographic documentation whose results were compared with literature evidences. This was necessary to distinguish organic materials according to photosensitivity classes in relation to their degree of aging and photochemical degradation, in the perspective of their protection and preventive conservation as suggested by current standards.

2.2. Photometric and colorimetric measurements

In the present section the experimental photometric and colorimetric measurements are presented and discussed. The illuminance levels were measured at each point of the mesh by the standard technique with digital luxmeter. The measurements of the horizontal illuminance were carried out on grids of different dimensions, on the floor and all the perimeter walls, to which a number of different measuring points corresponds. An operative and procedural methodological scheme to reduce the executive time and improve the sequencing was defined. Three series of experimental measurements of illuminance levels, were carried out on each point of the grid, waiting for the stabilization and calibration of the instrument. In Figure 1 experimental meshes used and the corresponding measurement points are shown.

The measurement technique with spectrophotometer, applied on surface portion with dominant colour of the frescoes, was the method for measuring the fraction of the visible radiation intensity that the same surface reflects by diffusion at different wavelengths. The change of spectral distribution of the reflected radiation, with respect to that due to incident radiation, provides the surface colour. In particular, to measure the characteristics of a painting/object illuminated by a specific source, it is necessary to choose a repeatable and standardized coded measurement method. This is crucial for measurement of a diffusing surface/object. We used an experimental set-up for which the light source was placed at 45° with respect to the object. Measurements were performed at the front (configuration 45/0), so that the specular light component was not present in the visual field of the instrument, that is the part of the reflective specular radiation of a particularly shiny object. Figure 2 shows the experimental apparatus used for the measurements. The instrument, equipped with a camera lens, "looks" at a given area on the pictorial surface and analyses diffused light coming from that area. Quality and quantity of diffused radiation depend on the measuring point and light, with which the surface is illuminated, and the reflective features of the pictorial pigments (e.g. blue, red, gold, etc.). If the illuminated surface is not a picture or an object but a white diffusing surface (the white reference tile, Spectralon® Labsphere), the reflected light from it, is identical to that emitted from the light source: spectral characteristics of each tested light source were obtained. The spectrophotometer was connected, through a RS-232 serial cable, to a notebook, for continuous data acquisition. The numerical values that describe the spectral curve, luminance (LV) and chromatic coordinates (x, y), that are a measure of the light colour, were deduced. It was used together with its own white reference tile, to measure the spectral distribution, luminance, chromaticity and colour temperature of the tested light sources. Accurate measurements of electromagnetic radiation in the visible spectrum were also carried out.

Some tests were performed at the CNR-INO laboratory to verify method reproducibility, before achieving experimental measurements in situ. Five consecutive measurements were conducted on the same white stimulus: the luminance value obtained was $L = 79.11 \pm 0.04$ cd/m^2. Then, five different measurements were made: after each one there was a five minute pause and after reproducing the white stimulus at the PC monitor, the measurement was performed again. In this last case the luminance of the white stimulus was $L = 79.00 \pm 0.08$ cd/m^2. These two measurements are comparable: this guarantees measurement repeatability and the method validity. Standard deviation of all the experimental data, provided an error that is much lower than 1% corresponding to instrument accuracy. The experimental error is not shown because it is smaller than the point size in the corresponding graph. Technical data of instruments used are: Eye Tracker-Tobii-Glasses 2, with dark pupil Corneal reflection, 30 Hz sampling rate and four sensors; Spectrophotometer/radiometer CS 1000 Minolta, with 380-780 nm wavelength range, 5 nm spectral bandwidth, 0,9 nm wavelength resolution, ± 0,3 nm spectral accuracy and 0,01-80000 cd/m^2 Luminance range; Luxmeter CL-200 A Konica Minolta, with a silicon photocell of spectral responsivity within 6%, 0,01-299 900 lx measuring range and ± 2% ± 1 accuracy.

2.3. Perception experimental measurements

The observation (vision and perception) of works of art is a complex process conditioned by different factors. There are two approaches for understanding the perception process: the *top-down* processing concerns the pattern recognition development by use of contextual information; in the *bottom-up* processing perception starts at the sensory input (stimulus) and can be described as data-driven from the retina to the visual cortex in the brain. The salient features of an image (contrast, luminance, colour, dynamism) influence ocular movements: in particular, colour improves the perception of details and the number of observed elements, increasing their complexity. Starting from fundamental studies concerning psychology, Gestalt-psychology and neuro-(brain)-sciences, eye-tracking technique application was used to understand how and how much a specific light source affects vision and perception processes. The Tobii Pro Glasses2 [17], equipped with a functional unit for data collection Tobii Pro Glasses Controller and the software Tobii Pro Analyzer for the output data processing, was used. The eye tracking measurements were performed on a sample of 15 participants (women and men), aged between 20 and 25 with normal vision. The eye-tracker instrument records all the eye movements and behaviours related to perceptive and cognitive mental activity. Tobii eye-tracker wearable glasses recording data at a frequency of 30 Hz were used: they are easy to wear and do not require that the participant be accompanied or supported. Using Tobii Studio software the visual scan path with the corresponding stimulus can be overlapped. Before proceeding with measurements the Tobii Pro Glasses2 was calibrated on each observer for recognizing the convergence coordinates of gaze. The following sentence at the beginning of each test was read: "*During the experiment you should concentrate on the wall painting, trying to exclude, as far as possible, the boundary and expressing your own preference for the fresco, as the selected light scenography changes*". The LED sources were positioned at a distance of 3 meters from the wall paintings; the distance between fresco and participants was 1,5 meter. The experiment was divided into three tests corresponding to the three tested light sources. During each test the fresco was lit in sequence with each different LED for 15 seconds. At the end, each observer expressed her/his preference for the first, second or third light source. The method was validated comparing experimental setting, measurement protocol, boundary conditions and results with basilar literature researches on eye-tracking technology applications [2, 3, 18, 19].

3. Results and analysis

3.1. Photometric and colorimetric experimental measurement results

Photometric measurement results showed darkness of the room: the chandelier was kept on, for all the time of the measurements, in order to maintain the real conditions, the mean illuminance value is 12,5 lx, in the presence of 24,2 lx maximum and 3,4 lx minimum value. The mean illuminance values, obtained as the average over the three series of measurements at each grid point (refer to Figure 1 for experimental grids and measuring points) are: for the wall that divides the two rooms 15,9 lx; for the wall of two inaccessible rooms 11,6 lx; for the floor 10,5 lx. Balance and uniformity of illuminance is completely absent because its limit ratios are less than those suggested by the standard: the calculated ratio between the minimum and average illuminance value, and between maximum and average illuminance values are respectively 0,27 and 1,94. The experimental error data analysis, using Pearson standard deviation calculation, provided an average error of 4,5% over all the measures of illuminance: therefore, measurements have good reliability and validity. Three lighting sources were used for optical-perceptive measurements: a LED Vivid Warm Plus (VWP), a LED Vivid White (VWh) and a LED Standard (STD). Their main component is a COB (Chip On Board) light source with a combination of specific LEDs with specific phosphor mix and with nominal light beam opening up to 120°. Their secondary optics are provided by a combined diffusing/shielding, diffractive/shielding system that works with a front closure in extra-clear tempered glass, up to 60 ° nominal opening of the light beam. Nominal colour temperature of the three LED sources is: 3200 K for VWP; 3000 K for STD and 4100 K for VWh LED. Results obtained for the three LED sources illuminating the white reference tile, and their spectral characteristics are provided in Figures 3-5.

Figure 1. The meshes used for measurements.

Their spectrum is the typical LED spectrum, i.e. with a first peak marked around the 450 nm wavelength and a second peak around 600-650 nm wider, due to the fluorophores (yellow) deposition whose emission is excited by the same blue light at 450 nm wavelength. Comparing the results obtained for the VWP and STD, differences between their spectra are due to the greater presence, especially in VWP, of radiation in the wavelengths between 500 nm and 550 nm, and also in the displacement of the highest peak from 600 nm to 640 nm. This fact, although it does not produce appreciable colour temperature differences (i.e. from 3062 K to 3091 K), however moves the colour point on the chromaticity diagram CIE1931, with respect to the black body curve, the x coordinate from 0.43 to 0.42 and the y coordinate from 0.40 to 0.38. Since x and y lower values correspond to spectra with more green-blue light. From measurement results it can also be noted that the tested LEDs have a very similar colour temperature but different from the nominal ones.

From comparison between the emission spectra normalized on a 450 nm wavelength for the three LEDs and their correspondent colour point of light, it can be deduced that: VWP has a maximum emission peak between 620-650 nm, corresponding to red colour; STD has a maximum emission peak between 580-610 nm in correspondence of the yellow-orange colour; VWh has a maximum emission peak between 440-460 nm in correspondence of light blue/indigo colour. Comparing the colour point of the three light sources on the CIE chromaticity diagram, it is possible to deduce their colour temperature: for VWP is 3047 K, for VWh 4049 K and for STD 3782 K. It can be noted that VWP has a strong yellow/red component compared with blue. In VWh there is a strong blue component compared with red and in STD the two components are quite well balanced.

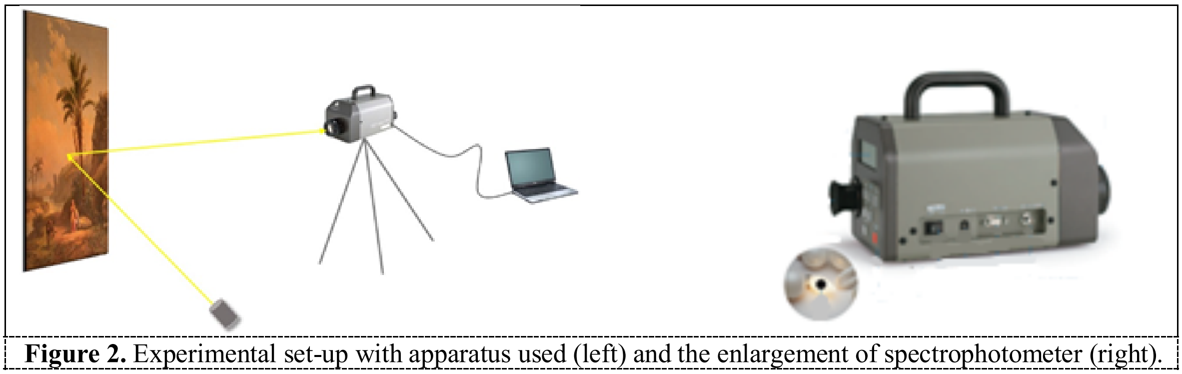

Figure 2. Experimental set-up with apparatus used (left) and the enlargement of spectrophotometer (right).

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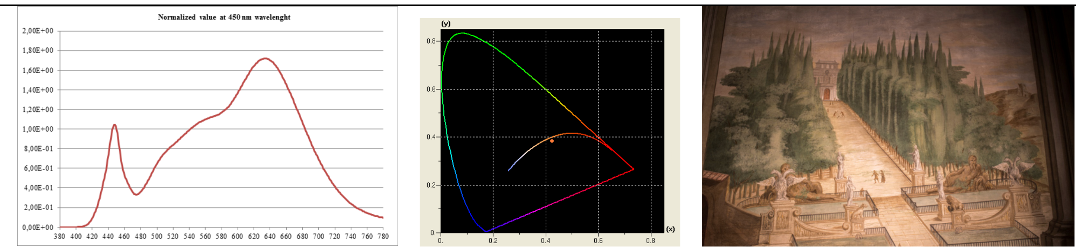

Figure 3. Spectral emission normalized at 450 nm wavelenght (left); Chromaticity diagram xyY CIE (center); real wall fresco lighting (right) - VWh 4100.

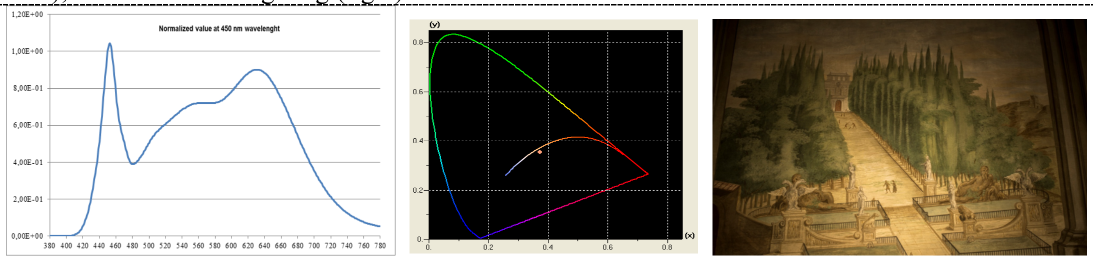

Figure 4. Spectral emission normalized at 450 nm wavelength (left); Chromaticity diagram xyY CIE (center); real wall fresco lighting (right) – VWP

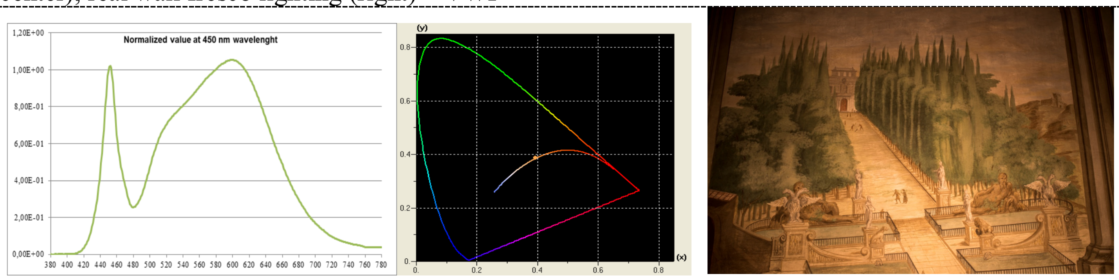

Figure 5. Spectral emission normalized at 450 nm wavelength (left); Chromaticity diagram xyY CIE (center); real wall fresco lighting (right) - STD 4000

3.2. Light experience and perceptive experimental measure results

From the Tobii-Studio program, the data post-processing was made and results were mapped. The following indexes were obtained: visit number, visit duration, gaze number (number of times that the eye stops on different areas), fixation number (number of micro-movements of fovea occurring during visual path), time from the first gaze and time from the first fixation. The assessment of the above indexes allowed the knowledge of the exact instant in which the eye has focused a specific zone of the fresco connected to the visit numbers and then the activation of the neuro-cognitive processes (i.e. interpretation and representation of the visual stimulus). Gaze data comparison allowed the definition of the areas of interest (AOI, targeted by Fixation Count and visualized by the HeatMap) that is the fresco zones with the highest number of visits. There are three identified AOIs: the landscape-park; the courtyard with the statues; the avenue with the building at the back (Figure 6). Referring to the time of the first fixation, the visit path of the observers was evaluated: for all the subjects the visual path moves from the centre of the fresco, towards the sides, to go down to the courtyard with the statues. Gaze plots show the location, order, and time spent looking at locations: they provide time sequence of looking expressed as fixation duration, quantified by the diameter of the fixation circles (i.e. the longer the look, the larger the circle; Figure 7). An initial general analysis suggests that data collected from 15 visitors follow a consistent pattern when observing the fresco. The AOIs identified on the fresco, were shared by most visitors and then the order (visual pathway) was similar for each of them. In particular, 54% of observers preferred VWh. The ratio between higher fixations number and less visits number provided

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indication about the lower entropy (i.e. higher neg-entropy or information content) because fixations tend to be concentrated on a certain AOI that appears to be more interesting.

As a matter of fact, the value of this ratio for the three different LED lighting, is: for VWh 5,26 AOI-courtyard, 2,6 AOI-threes-right, 2,2 AOI three-left, 3,6 AOI-avenue, 2,4 AOI-sky; for VWP 3,5 AOI-courtyard, 2,3 AO- threes-right, 1,8 AOI-three-left , 2,5 AOI-avenue, 2,1 AOI-sky; for STD 3,9 AOI-courtyard, 2,4 AOI threes-right, 2 AOI three-left, 2,8 AOI-avenue, 2 AOI-sky. The AOI-courtyard shows the highest gazes (Figure 7). The percentage of time, during which an AOI was fixed and observed under the three LED lighting, compared to the total time of analysis is: for AOI- courtyard 9,79% VWh, 9,14% STD, 8,71% VWP; for AOI-threes-right 2,95% VWh, 2,17% STD, 1,83% VWP; for AOI three-left 4,85% VWh, 4,01% STD, 3,78% VWP; for AOI-avenue 8,94% VWh, 7,18% STD, 6,78% VWP; for AOI-sky 1,18% VWh, 0,89% STD, 0,78% VWP. The greatest variations in time and fixation numbers of each area depend on the type of light source: higher concentration, processing of visual stimulus, visual scanning patterns with many fixations oriented to an AOI before moving to another, perception and then lower transition entropy (i.e. higher neg-entropy or information content transmission; [14,15]) are obtained with colder light, i.e. the VWh (Figure 8).

Figure 6. Areas of interest AOI

Figure 7. Gaze Plot: STD-LED, top left; bottom centered, WP-LED; top right Vivid-White-LED

Figure 8. Heat Maps: STD-LED, top left; bottom centered, WP-LED; top right Vivid-White-LED

4. Conclusions

The post-processing of experimental data showed that the highest amount of visual explorations and fixations are detected in those AOIs where contrast, duration and number of fixations are higher, and then where the information content (neg-entropy) is greater, consisting of simple but complex visual stimuli, because they are immediately recognizable when they recall to the memory of the subject his/her past experience and activate his/her embodied simulation (i.e. the emotional visual experience due to

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the activity of mirror neurons that allow mapping on the same nervous substrate images/actions performed and observed, feelings/emotions experienced and observed on ourselves and on others).

Comparison between the eye-tracking results and LED lighting parameters allowed checking of how the colour of light changes the observer's perception, and from the information theory point of view, the communication and interpretation process of different signals due to different light.

This study allowed us to evaluate how light colour affects perception: In particular, if the AOI were common to most visitors, the order and observation priority (visual pathway), was different: this constitutes that "common sense" that light, as a visual-perceptive experience can return in the transmission-communication of neg-entropy. Method and results of our research belong to a pilot project that we would like to develop in order to provide guidelines for effective lighting solutions (not only for museums) because they are imagined, structured and designed for the quality of vision and perception and, in other words, information transmission or visual light communication.

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