How the colours of objects and light affect human emotions, performance and health. The need for a holistic approach to design indoor environment.

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ABSTRACT

Colours and lights have been shown to influence mood and performance, "cool colours" like blue and green are relaxing and peaceful to the eye, whereas "warm colours" such as red and yellow seem activating and arousing. Cool light, rich in short wavelength radiations, has also a significant effect in terms of circadian rhythm synchronization by inducing melatonin suppression.

For colours to be used in industrial objects, social and cultural factors also play a significant role.

The choice of colours in indoor environments, for both objects and light, should thus be done considering all these aspects. However, these different approaches lead to different points of view and to hardly comparable results. Also, the design process is unique and the final user is not able to distinguish between colour perception, visual and non visual effects of light as well as messages that can be expressed by means of colour patterns.

It appears necessary to establish reciprocal interactions among the different disciplines involved in the choice of objects and light colours, and namely among researchers in medical science, psychology, lighting and industrial design, in order to assess an interdisciplinary methodology that can be applied to indoor design.

KEYWORDS Identity, Quality, Visual Context, Indoor Environment, Perception, Properties, Circadian cycle

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1. Introduction

Colours and lights have an influence on humans' mood and performance (Bourgin and Hubbard, 2016; Ou et al. 2004). Indeed, in an indoor environment, walls and furniture colours affect the perception of the space and induce different psychological states (Yildirima et al. 2007). In the scientific literature several experiments have been carried out to study colour preferences and emotional effects, also looking at different contexts and application. Despite the use of different methodologies and visual tasks, findings are generally in agreement in asserting that "cool colours" like blue and green are relaxing, calming and peaceful, whereas "warm colours" such as red and yellow result activating and arousing (AL-Ayash et al. 2016).

All experimental research performed on the circadian effects of light demonstrate that cool light, rich in short wavelength radiations, has a greater effect in terms of melatonin suppression (Brainard et al. 2001). Blue enriched light, i.e. lights with a great amount of short-wavelength radiations and CCT greater than 10000K have a positive effect both on seasonal affective disorder (bright light reduces SAD symptoms) and on cognitive performances in educational and office environments, stimulating attention and alertness (Thapan e al. 2001; Viola et al. 2008).

From the above considerations it seems that the choice of colours in indoor environments, either for objects and for lights, should be done considering both their physiological and psychological effects. Actually, things are much more complicated because it should be also taken into account that, in the choice of colours for objects and specifically industrial objects, social and cultural factors play a big role.

Despite those different approaches lead to different points of view and to hardly comparable results, we must not forget that the design process is unique and that the final user, i.e. an observer in an indoor environment. is not able to distinguish between colour perception, visual and non visual effects of light as well as messages that can be expressed by colour patterns, whatever the application can be (office, shop, school, hospital, etc.). On the contrary, they globally perceive whether the lit environment is pleasant and suitable, for the specific activity to be performed, regardless of the specific strategy the designer could have adopted.

Given these premises, it appears necessary to establish reciprocal knowledge and interactions among the different disciplines involved in the choices for objects and light colours, and namely among researchers in medical science, psychology, lighting design and industrial design. The aim of this paper is to discuss these interactions, by comparing the different approaches, in order to find some common grounds and develop integrated research activities.

2. Objects colours: identity and quality

Colour represents the first visible item of the identity of a product. It characterizes the quality and therefore it is the subject of a complex cultural assessment, which over the years has been substantially changed (Pine, 1993). The approach to colour should also be framed within the more general definition of industrial product quality.

For decades, the idea of product quality has been associated exclusively to performance aspects. Over time the increase of the cultural dimension in all product activities and consumer patterns has shifted the focus towards more complex and less immediate aspects than those purely functional in defining the qualitative components of a product (Carmagnola, 1991; Garvin, 1988).

A first phase of motivation in colour choice is related to the need for early serial industrialization.

The role attributed to the choice of colours in the production in this period of history, can be synthesized by the famous phrase of one of the protagonists of mass production, the American industrialist Henry Ford. He summarized with the following sentence the need to limit colour choice and to adjust its production process which was characterized by a single assembly line: "Any colour in the choices of a car is permissible, as long as it's black".

It was precisely through this peremptory affirmation of Henry Ford, about the lack of choices other than black, that started the first theoretical formulations of those principles of standardization at the base of mass production.

The monochrome trend in the early mass industrialization, the “only black” of “Fordism”, launched a message of product longevity, opposed to the polychromy transience which expressed the rise, in the same period, of the fashion phenomenology. However, it is precisely around the expressive power of colour that the gradual overcoming of “Fordism” occurred, replaced by a plurality of languages. Attention to the chromatic expression has gradually focused towards the search for an interaction between the user and the product that has been a central point of the various theories of colour, starting from the one by Johannes Itten and the painter and his student Josef Albers who, in order to summarize this process, introduced the concept of "epidermis of materials" (Albers, 1963). Since the first half of the 20th century, just starting from Itten's colour research within the Bauhaus educational programmes, a specific attention to colour themes in industrial production has been confirmed. A very interesting field in which these transformations can be observed is that of the typewriter. At the beginning of the mechanization of writing, between the first and second decade of the last century, we find machines with some common features in all production systems: strong mechanical standardization and the exclusive use of the fired enameled black colour for the frame (Giedion, 1948). When in the early 1930s many European engineering industries decided to launch the first portable typewriter for private users, the first tangible sign of this little revolution was just assigned to the colour. To the traditional and exclusive black of the first series, a wide variety in the choice of colours was added. In 1932, for example, Olivetti launched its first laptop for home use, the MP1, it was built in seven colours: red, blue, light blue, brown, green, grey and ivory. The first customization in the industrial production season had started. The small mechanics began to enter homes through the lightness of colour, by adapting to the variability of domestic furniture. The first portable Olivetti of the thirties and forties will be followed by Nizzoli's "Letter 22", which will be one of the Italian design icons of the 1950s. Nevertheless, it is thanks to the post-rationalist revolution of the sixties that product hyperchromatization was used as a metaphor for the Young Revolution. In 1968, the "Valentine" by Ettore Sottsass and Perry King represents the most evident case of POP culture chromatic exacerbation. For the first time, an industrial object, just like any other item of clothing would do, adheres both to the worlds of production and communication (Brusatin, 1983).

This opens a road, which leads to present days, where the translucent white colour and the brushed aluminium of Jonathan Ive's Apple products finishing is the main iconic brand identity element and, more than any other, is the true image of modernity (Castelli, 1999).

It is due to this ideological character assumed by colour in relation to the product, it is through this subject that it is possible to recognize the border between the product and the brand in current industrial production. Studying the different ways how an object, as well space, from a physical matter, becomes the privileged place of brand communication, one discovers that colours represent the matter that formalizes this step, and it can be also considered as the threshold point between the abstract and the real physical space.

The chromatic experience allows us to understand the first transformation of goods, from necessary objects for basic needs to desired dream objects. Around the mid-19th century in Paris, with the "Passages", indoor malls were created. A busy social area with shops, cafés and theatres. Here the skylight, covered with thin layers of glass filtering the natural light, emitted a bluish colour cast that surrounded people, goods and architectures, placing spaces and products in an immaterial and oneiric dimension (Codeluppi, 2000).

After this first example, colour, owing to its mnemonic strength, has always been, starting with the primary red Coca Cola label, and together with the logo, the main element of brand recognition. In addition, colour is one of the elements around which a brand name in a shop is characterized.

3. Light and objects colours

As far as interior objects and walls colours are concerned, architects and interior designers should take into account lighting, both for its spatial and spectral characteristics. Nevertheless, human visual system is characterized by a good "colour constancy", this is true especially for daylight whereas, in presence of electric light, sources SPDs can sometimes significantly affect colour perception. Indeed, light stimuli that reach the eyes are a combination of sources SPDs and materials spectral reflectance and transmittance; however, this is not sufficient to predict how the colours are perceived and whether they appear pleasant and realistic. The visual context in which objects are observed and human visual system adaptation have a big influence in object perception.

In the lighting design practice, the chromatic characteristic of light sources are synthesized by two main parameters: correlated colour temperature (CCT) and colour rendering index (CRI). Before the diffusion of LEDs, these parameters were quite indicative and useful for lighting designers to determine their choices, but modern standards now call them into question.

Spectra rich in short wavelengths in the visible range are characterized by high CCTs (cool light), whereas spectra rich in long wavelengths correspond to low CCTs (warm light). Daylight is characterized by different CCTs, depending on the solar position on the sky vault, cloudiness, and if considering only the sky or the sun or both. D65 standard daylight illuminant CCT is 6500 K, whereas north blue sky CCT is between 10000K-20000K and, if considering sunset/sunrise light, very low CCT values are attained, around 3000K. As typical indoor electric light sources are concerned, incandescent halogen lamps CCT values range between 2700K - 3000K, fluorescent lamps are available at different CCTs, between 2700 K and 6500 K as well as LED sources, which can reach even higher values (7500 K). Moreover white tuning LED light sources currently available allow to change SPDs according to users' preferences or to change other conditions, such as light scenes, time of the day, illuminance levels, etc. In designing an indoor lighting system, besides luminaires dimensioning and photometric choices, CCT is a topic of concern. (Kruithof, 1941) established correlations between illuminances and preferred CCTs, and more recently, (Viénot et al. 2009) demonstrated that, with LED sources characterized by very high CRIs, most results are in agreement with Kruithof's original findings, but with some exceptions, concluding that more researches are necessary. Moreover, since the advent of LEDs, the colour rendering index (CRI) has revealed some shortcomings and for this reason new indices were proposed as in (Li et al. 2012; Smet at al. 2019) and a CIE Technical Committee (TC 1-90) was established in order to produce the Technical Report "CIE 2017 Colour Fidelity Index for accurate scientific use". Basing on some of the findings obtained by these researches, the ANSI/IES TM-30-18 Standard (ANSI/IES, 2018) proposes a method for evaluating light source color rendition, quantifying both average properties (color fidelity, gamut area) and hue-specific properties (fidelity, chroma shift, hue shift) of a light source. This Standard, characterized by an objective and statistical approach without considering subjective evaluation, has been currently adopted in the USA and in other countries. At the same time researches from all over the world proposed other indexes useful to describe the "colour quality" of a light source (Teunissen, 2016; Lin et al. 2016; Smet et al. 2016; Jost-Boissard et al. 2015). From the above considerations it can be stressed that, when speaking of "colour of light", many aspects are involved and that the final effect is done by the combination of light and spectral properties of materials. The question is: "given the great availability of spectra, what is the best light for a given environment?". But at the same time: "what are the best colours for objects and walls in a given environment?".

These two questions cannot be formulated separately, probably a better question is "what is the best combination of light and objects colours?". The possible answers are not easy, because if on one side cultural and social choices are performed, on the other material and lighting technologies offer new capabilities.

Even with an attempt of a brutal simplification, for example in the choice of "warm" and "cool" colours both for objects and for light, many contradictions arise: red colour, for example is often associated to danger and alerting, whereas blue-green colours are chosen in hospitals walls because inducing peacefulness and calmness feelings.

However, considering also non visual effects of light, which will better examined in the following section, it has been proven that, under the same other conditions, cool light sources are more effective than warm ones in melatonin suppression (Rea et al. 2010). Furthermore (Viola et al. 2008) demonstrated that exposure to blue-enriched white light during daytime work hours improves subjective alertness, performance, and evening fatigue. Physiology of vision, effects of light on health and psychological aspects are to be considered as well, and easy results are not so immediate.

4. Visual and non visual effects of light stimuli

Visual and non visual effects of light occur by stimulating different parts of the eye- brain system. In the case of vision, light falling on objects activates a photo-transduction process, photo-receptors in the retina transform the physical signal into an electrochemical one which then activates the neural-vision process.

Specific properties of objects also determine the characteristics of the light which activates the eye-brain system. The final product of vision is what is called "perception", physical properties of the external world are "seen" as objects by the brain. Perception is acquired using both intensity variation of the light and its spectral variation leading respectively information on luminance and chromatic characteristics (Moutossis, 2016). Sensitivity to luminance and chromatic characteristics are advantageous for an organism, allowing information helpful in a visually noisy environment; Indeed primates have three different types of light-sensitive cone cells, instead of two as in other mammals, that allow a better colour discrimination. Furthermore, colour vision gives what are probably the most important signals for the psychological characterization of the perceived object. Colour gives information about vital signals, sexual signals for reproduction, as well as information on health and emotional states.

The non visual signal is central for the synchronization with the external timing of light and dark, which organizes the life and behavior of the living species, and photosensitive retinal ganglion cells (ipRGCs) that contain the photopigment (melanopsin) are mainly responsible for the information regarding light (Graham and Wong, 2016).

These cells are able to incorporate light signals over an extended period of time resulting in an increase of sensitivity during prolonged light stimulation, ipRGCs are most sensitive to wavelengths that are in the blue region (λ max = 482– 484 nm) of the light spectrum which is also close to the light spectrum (λ max = 459 nm) responsible for melatonin suppression.

Current light environment however differs radically from the one animal species and our ancestors experienced during evolution. The most dramatic changes occurred at the end of the nineteenth century with the introduction of electric light that has produced an artificial prolongation of natural daylight and the suppression of the seasonal lighting cycle, with important changes in human behavior and physiology (Wehr et al. 1993).

Furthermore, in recent years the "artificial light revolution" together with the progressive reduction of the natural light exposure due to energy saving building design, has produced a significant variation of the natural 24 h light/dark cycle leading to around-the-clock artificial lighting that differs markedly in spectrum, intensity and temporal patterns compared to natural lighting.

Daytime sunlight is necessary for circadian clock synchronization as well as for vitamin D synthesis, a regulator of several biological processes, and nighttime darkness is also necessary for melatonin synthesis, the hormone which contributes to regulating the physiological processes occurring within the so called biological night. Thus the 24 h external day/night cycle synchronizes the suprachiasmatic nuclei that regulate the circadian oscillation of human activity and rest (Smolensky et al. 2015).

Currently available light sources (LEDs) are often rich in short wavelengths in the visible spectrum (improperly called "blue light") and even low intensity of such blue light is capable to attenuate or suppress melatonin synthesis producing a significant sleep disturbance. This light spectrum, on the other hand is capable of reducing sleepiness effects and thus can be used to alert subjects when this effect is necessary (Lockley et al. 2006; Phipps-Nelson et al. 2009; Sahim and Figueiro, 2013).

Non visual effects of light can be analyzed by measuring or calculating spectral irradiances at the eye-level and, especially in indoor environments, they depend not only on light sources SPDs but also on spectral reflectance of walls and furniture: in other words they depend also on walls and furniture colours. As a general rule, in order to achieve very comfortable visual conditions, it's recommended to avoid that direct light from light sources strikes on observers' eyes, so often indirect light, as a result of multiple reflections, assumes a relevant role in affecting spectral irradiances at the eyes level (Bellia et al. 2017).

Obviously both visual and non visual effects of light depend also on intensity besides SPDs. Indeed, the choice of surfaces and furniture colours with different reflectance factors affect the amount of light reaching the eye. Light colours for walls are to be preferred for most applications, in order to increase adaptation luminance and illuminances both for visual comfort and energy saving.

5. Conclusions

When we look at an object located in an environment, the colours of both these components should be considered, since the object transmits a message and the environment has a specified identity. The light stimuli at the eye are given by the radiations coming from the object and from its surroundings (context). In this phase, lighting (i.e. primary sources) takes up a relevant role as well as the spectral optical properties of the lit surfaces. Given these stimuli, the human visual system performs an adaptation involving all eye components (pupil diameter, rods and cones pigmentation or de-pigmentation, lens thickness, etc.), then sensorial cells (rods, cones, ipRGCs) transduce these stimuli into electric signals and neuro-transmitter cells send these signals, properly processed, to the brain cortex. Through very complex mechanisms these signals are sent to different brain and body areas, for different purposes, like the regulation or activation of the circadian rhythm, or the perception of the object and its surroundings, also involving different cognitive activities. So, a physical stimulus (light) coming from the surrounding environment is processed by the eye-brain system in multiple ways in order to guarantee survival and for other secondary purposes. This can be the reason why light signals, received by different areas, could induce contrasting effects: a cool light could be "melatonin suppressing", throughout ipRGCs-SCN pathway, but at the same time being perceived as relaxing throughout the eye-brain cognitive processes. This complexity is accentuated by personal experiences as well as by subjective cultural and social backgrounds.

For these reasons, when approaching the theme of the choice of objects and light colours for indoor environments in order to obtain proper visual conditions, enhance human performances, regulate circadian rhythms, satisfy esthetical, cultural and social expectations, it is very difficult to find a solution that fulfill all the requirements and at the same time result satisfactory for most people. As for all complex problems, each of the factors that concur to a good environmental quality and to visual aspects should be addressed . Indeed, these factors involve very different branches of knowledge, as medical science, psychology, interior design, lighting design, as well as the technology of materials and lighting. Considering only some of these branches and neglecting the others could lead to great mistakes. One initial obstacle is that nomenclature and language for the different branches sometimes strongly differ, creating communication problems. On the other hand, many intersections can be detected and the same subject of study, and can be seen by different points of view that, altogether, can better explain some phenomena or harmonize apparent contrasts.

It appears thus necessary a really "human focused" methodology which bonds knowledge from the different fields to produce an environment able to satisfy those several needs. An ideal indoor design should consider not only the daylight availability, the electric light and its possible manipulations to guarantee the adequate photometric parameters for the room's purposes, but also the window design, the interior colour of walls and furniture, and all these variables should be fine tuned to allow the comfort and wellness of the final client that is the human being. Experimental procedures on colour/light manipulation that take into account the human factors should be further implemented to better understand effects of such physical entities on emotion and cognitive performances

6. Conflict of interest declaration

The authors 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, their work.

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