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Invited Paper

Lighting a Smart Society

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ABSTRACT

Lighting is no longer just turning on a lamp. Solid State Lighting allows reaching high energy savings and visual perception, but the path to success was not easy: in the early years when LED were available on the market, several concerns slowed down their widespread implementation. The large spread of Lighting Systems based on LED arrived only when products quality increased thanks also to the development of new metrology paradigms able to certify LED performances peculiarities. Currently LED promises to widespread in every lighting application increasing not only energy savings, but night-time safety, health and wellbeing thanks to lighting systems based on connectivity and smart controls, but new design paradigms and metric headed to new objectives are necessary, therefore there will be no need to measure only energetic and light performances. We are moving toward an approach more sensitive to Human Needs: energy savings and light efficiency are of no more the only interest to focus on, we need to measure performance of a lighting system in terms of not only SI quantities. We need now a consolidated metrology and design approach to *Smart System* for complexity and suitable to compare lighting quality in term of human perception and wellbeing.

Keyword list Smart Systems, LED, Perception, Soft Metrology, Lighting Quality, Systemic Design, Digital Society, IoT

1. INTRODUCTION

Light has a distinguished relevance on several aspects of our society. Its relevance is recognized even by the metrology: light is just an electromagnetic (e.m.) radiation, but has its own language, e.g. measuring units. The luminous flux is measured in lumen [lm] the intensity in candela [cd], because the e.m. radiation is weighted, in the so called visible interval (380 – 780 nm) by luminous efficiency function for photopic vision $V(\lambda)$ (def. 17-731 [1]), representative of CIE standard photometric observer sensitivity to the different wavelengths of visible interval (e.g. the human sensitivity in daylight condition of adaptation) and by the luminous efficacy K_m (def. 17-730 [1]) that is the bridge between light and e.m. radiation connecting the physical units of lumen and Watt.

The biological relevance of light has been proved by several experiments started in the fifties [2,3] that clearly demonstrated that the circadian system (biological rhythms of cortisol-melatonin production) of animals is sensitive to light variations, mostly during the biological night, proving the biological relevance of artificial light. Indeed some argue that artificial light changed our biological behavior in nighttime, including the natural time sections of sleep [4] artificial light is the main engine toward a "twenty-four/seven always connected" society. Actually, researchers demonstrated that light is capable to produce a phase shift up to 12 hours of circadian system [5] on humans being exposed to artificial light during the early-biological night or late biological day (two definitions of day phase based on the biological rhythms of circadian system). But the human circadian system is so sensitive that can be influenced even by very low levels of light (candlelight) [6], so the suggestion [4] that artificial light influenced our natural behavior is no more unlikely. Following studies considering spectral influences demonstrated a short-wavelength sensitivity [7] that only recently, because of blue light amount in LED (Light Emitting Diode) sources, is worldwide discussed may be also with too much alarming in non-scientific publications and framework.

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From the technological point of view the last fifteen years provided large technological advances in terms of mass production of innovative lighting sources, control devices and design tools that are driving the economic market. It is estimated that the lighting market will get a growth bigger than 50% in 10 years length (2011-2020) due to population growth, urbanization and, especially, an increased interest in energy efficiency and environmental respect.

The energy savings was the advantage that leads the Solid State Lighting (SSL) market spread more than ten years ago, but only when a dedicated metrology [8] to estimate LED peculiarities was available, LED had a truly large implementation. Products quality increased when new metrology paradigms able to certify LED performances peculiarities and new design approach were available too. Initially market underestimated the intrinsic metrological peculiarities of SSL in terms of performances, and of scientific knowledge needed for lighting systems design. LED sources need more scientific knowledge of radiometric, photometric and electronic peculiarities of sources, and LED-human observer reciprocal interactions that many installations went wrong.

Unfortunately in the next years, energy savings is condemned to decrease. In the future the expected potential saving (6%) due only to sources will be very less significant than the big step achieved at the introduction of LED (for the same amount of light of an incandescent source the electrical consumption of a LED source is about one tenth: 200lm/W efficiency emission against 20lm/W of an incandescent lamp). Significant additional savings can be achieved only by *Smart* lighting *Systems* specifically designed.

Currently the metrics we have for appearance prediction of lighting environment are based on researches and subjective experiments with sources like fluorescent o incandescent lamps, with completely different spectral and spatial emission from SSL. SSL and LED have peculiarities that strongly influence not only the visual behavior (e.g. the current metrics for color prediction and glare fail with LED), but also the biological response (e.g. the so called non visual effects of blue light). To reach the highest benefit of SSL it is not a matter of light bulb substitution, but of integration between *Smart Systems* and SSL and a metrology able to quantify peculiarities not ascribable to mere SI units like the source intensity (luminous intensity measured in candela, /cd) or light falling on a surface (illuminance measured in lux, /lx), but more related to Human perception and wellbeing. This type of metrology is called *Soft Metrology*: a metrology covering “a broad range of measurands – called soft measurands - , addressing all the aspects of measurement, outside of the traditional field of physical and chemical metrology” [9].

2. SMART SYSTEMS FOR A SMART SOCIETY

A modern product design approach, if seen from the point of view of a Smart Society, is based upon the idea that human being is one of the nodes of a complex system where the environment, the resources, the quality of life (from a wide point of view) and the effects of each node onto the others are all converging towards a global asset of effects: the entire planet is a complex system by itself, so that each subsystem is node of a larger one.

Such kind of condition cannot be managed with a traditional approach, thus making sense to a new, broader vision of connections between fields that were previously managed individually. To achieve this goal it is necessary to adopt new strategies by design, in the methodology and in the tools used: a Systemic Design approach could be one of those possibilities, thanks to its capability to challenge the complexity while keeping the designer focused on the final, practical results [10].

In such kind of condition, even a very specific and technical field like the lighting for new society needs should be considered node of a more complex net, even more if we introduce hi-tech assets of devices, data gathering and management and, at last, people with basic but fundamental needs.

The digital society is rapidly developing toward a future that is not really clear, not mainly because of unknown parameters, but because too many information overlapping one each other while they are fast moving and changing. Again, another complex system to be managed that can be driven with a systemic approach only. The digital technologies are tools of a powerful kind, so it is really important to know exactly what they are, what can they do for us, how would the life be changed with or without them, so to make us able to choose the more aware solutions in each case, sometime deciding to even not adopt any kind of hi-tech solution, in favor of a more traditional one.

Such kind of awareness is not achievable with technical skills assessable with a **quantity** approach: a multidisciplinary approach, **quality** oriented, is needed in order to produce solid (not only design) decisions.

3. HUMAN CENTRIC LIGHTING

The road map of SSL lighting (see Figure 1) for the next 5-10 years is no more focused on energy savings, but rather to *Human Wellbeing*: we are now in the last years of the so called "LEDification" e.g. the large substitution of different light sources (incandescent, fluorescent and discharge lamps) with LED. But to move toward the next step called *Human Centric Lighting*, a different design and normative approaches as well large research on *ad hoc* predictive metrics are necessary. The same as it was necessary about fifteen years ago at the beginning of "LEDification": a metrology for SSL[8] to estimate LED peculiarities opened the path toward large energy savings thank to bulb substitution.

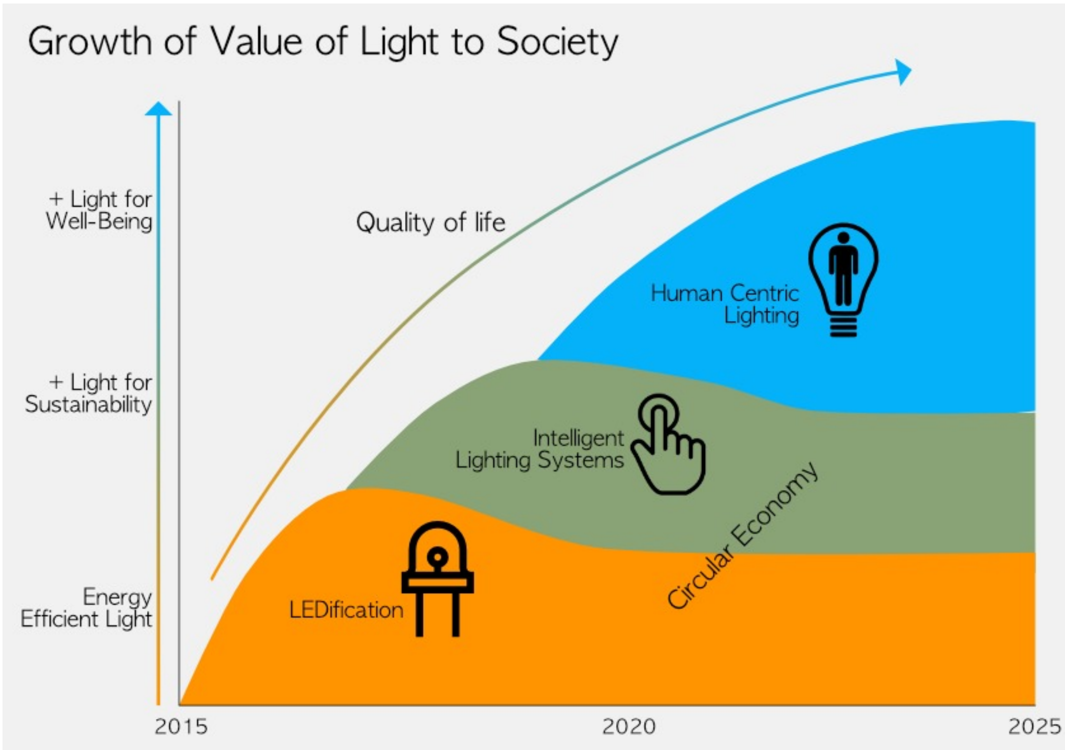

Figure 1. The SSL Lighting Road Map, as proposed by Lighting Europe [11]

Actually a widely accepted definition of *Human Centric Lighting* is not available. Lighting Europe[11], the industry association of European lighting industry, defines it as a light that "*supports health, well-being and performance of humans by combining visual, biological and emotional benefits of light*".

Human Centric Lighting needs LED source connected thought *Smart Systems* able to adapt to the environment and to user needs to assure not only the right **quantity** of light for vision (measurement of SI unit), but the right **quality** of the location including high quality light for vision and wellbeing (measured with the so called "soft measurands"[12]). It is expected that *Smart System* and Human Centric Lighting will permeate the market by 2025 (first systems are being installed in office buildings, hospitals and road lighting).

The simplest approach to *Human Centric Lighting* is to mimic the natural light scenario with a very basic *Smart System*: early in the morning and late in the afternoon like at dawn the natural light has a high content of red color (e.g. Low Correlated Color Temperature[1]), while at mid day when alertness and coordination are at the highest point and melatonin is not produced, the color of natural light has a lot of blue (e.g. High Correlated Color Temperature[1]). Pure biological effects like Melatonin production or suppression related to Correlated Color Temperature of light have been clearly demonstrated by biologist [13], but the challenge is not to mimic only the variability of natural light, but to design *Smart Systems* able to control light in term of intensity, spectrum and spatial distribution to assure to a human observer comfort, well being, safety, and better visual and not-visual performances knowing the interaction with human biology. Assessing all these aspects is very far from the "**quantity** approach" used since now to quantify in term of SI Units and specific measurands, are not available and generalist approach suitable for all possible applications is not possible. In the following paragraphs two different case studies driven by a **quality** and *Smart Systems* approach, both based on the metrological characterization of lighting sources, materials behavior, visual perception and Soft Metrology, are described.

4. CASE STUDIES

4.1 Lighting for Cultural Heritage

The first application we consider is an innovative Cultural Heritage lighting system able to achieve a defined appearance of the artifact keeping the light induced damaged at the lowest level. Usually conservation requirements for Cultural Heritage lighting are based on the "quantity approach": the maximum allowed level of light to minimize damage[14, 15, 16]. The methodology developed during the years [17] was recently applied to the Turin Shroud lighting exhibition of 2015 [18] and it is based on the knowledge of the Spectral Reflectance of significative Shroud points and innovative digital lighting projectors, Video Mapping and *Soft Metrology* experiment on visual perception. The lighting spectrum emitted by the projectors was calculated to achieve a desired perception of the Shroud (in terms of legibility of signs and color memory of the linen of pilgrims) assessed with *Soft Metrology,* producing the minimum amount of light (avoiding the most dangerous wavelengths for linen) assessed with SI units Metrology. The lighting set up was designed as a "map", in which each point of the lighted environment received a different spectral composition and light intensity providing the desired colour and contrast between figure and background compensating the influences of the protective frame. Due to the lack in predictive metrics, the best lighting solution was selected by a *Soft Metrology* experiment of visual perception involving Shroud researchers and pilgrims as observers. In this case is the source itself a *Smart System:* the lighting was designed with a *Smart* approach to enhance the whole visual experience and not only based on conservation constraint of measurement of SI units, i.e. the lux or Watt on the artefact. The methods exposed the Shroud to an amount of light 60% lower of the maximum allowed in standard [15, 16].

4.2 Road Lighting

The same scientific knowledge on radiometry, materials characterization and visual perception is needed for Road Lighting. Actually Road lighting is the only lighting application where **quality** approach is acknowledged also by European standard[19] and *Smart Systems* are already installed. The target of Road Lighting is to provide not only enough light to assure safety of road users, but also several quality parameters (mostly related to light distribution, glare and color recognition and comfort). The most recent advances in the visual perception are related to the definition of the luminous efficiency function for Mesopic Vision[20]: Mesopic is a condition of visual adaptation at lower light levels than daylight (Photopic vision) but higher than night-time light levels (Scotopic vision). For some specific road lighting environment it is possible to design lighting system according to performances for the aforesaid Mesopic visual condition. In mesopic SSLs give very promising results in terms of perception and energy savings. But not only: luminaires equipped with LED sources with *Smart Systems* can adapt not only the amount of light but also spatial distribution of light and spectrum to the environmental conditions (like rain or amount of traffic). *Smart Systems* can connect all lighting installations of a town realizing a sort of IoT lighting environment. The potentialities are wider than actual realizations directed only toward advertising and smartphone connectivity. In this future panorama of Road users smart and smarter because also the expected Autonomous Vehicles market launch in 2021, it is weird the commercial offer on the top level car market of Laser headlights[21]. These headlights are able to light the road up to 600m with the stronger source luminous intensity headlight: indeed the intensity is so high that safety of other road users (especially disability glare coming cars drivers) is an issue. It is clear that this market offer is driven only by the aforesaid **quantity** approach and doesn't suit well with the new trend of *Smart Systems.* A contribution toward road lighting **quality** approach is given by a growth in the knowledge of the spatial and spectral reflectance behavior of road surfaces to design *Smart* Lighting *Systems*, for this reason EU community funded the SURFACE project, a three years research project on Road Surface characterization for *Smart* lighting[22].

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