DESIGNING BEHAVIOURS FOR WELL-BEING SPACES

How disruptive approaches can improve living conditions

edited by Annalisa Dominoni and Francesco Scullica

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6. Color and lighting in the new healthy domestic landscape

Maurizio Rossi, Politecnico di Milano

Abstract

In the last 200 years, a radical transformation of society has taken place, the Industrial Revolution. People's activities have been transformed with mass migration from the countryside to urban centers and the development of industrialized societies. In a few generations, humans shifted from a life spent working in the countryside open air to one mainly in closed environments, with little natural light and subjected to artificial light. Observing this radical change in living environments that took place over a few generations, in this chapter, we address the complex question of the physiological effects of light and color in interiors on the health of human beings, which have been scientifically proven in the last twenty years. Besides, the risks and benefits to health arising from non-image-forming (NIF) effects of light are highlighted, and the limitations of light and color design in indoor environments compared to outdoor environments. Even though extensive neurophysiological research has demonstrated the importance of proper NIF management for human health, this is virtually absent in the design practice. Concerning these physiological effects, we also introduce the application implications that this scientific innovation is starting to have on the design methodology of residential interior design, in the delicate balance between natural light, artificial lighting, and colors.

6.1 Introduction: chronobiology, this unknown science

To understand the dimension of socio-economic change and the change in lifestyles, we consider that in Europe, in 1800, only 2% of the population lived in cities. It has been estimated that in today's industrialized world, people spend between 80 and 90% of their time indoors (Leech *et al.*, 2002; Evans, 2003; Mccurdy and Graham, 2003; Schweizer *et al.*, 2007; Boubekri, 2008). Based on this strong change in lifestyles, we can see that 200 years are nothing compared to the evolution of human beings and, from this point of view, the change of the environments where we live and our exposure to artificial lighting must be considered a factor of very recent introduction (Stevens, 1987). Under these conditions the light, the colors, the image of the surrounding environment perceived, differs considerably from the outdoors in which we have evolved for millions of years.

The word circadian, created from Latin words circa and diem, describes a periodic biological cycle that lasts roughly one day (Halberg *et al.*, 2003). The first scientist asking questions and observing the circadian rhythm was Jean-Jacques de Mairan (1729), with experiments on the Mimosa Pudica plant. He described that the opening of the flowers during the day and their closing at night persisted, also placing the plant in the dark, concluding that there is an internal biological clock that acts as in the plant. In the following century, the experiment on Mimosa Pudica was repeated, observing that the plant follows a cycle of about 22-23 hours (de Candolle, 1832). Despite these discoveries, many scientists rejected the idea of a clock in living organisms while supporting the existence of an exogenous factor due to Earth's rotation. They tried to find this factor empirically until the twentieth century when the foundations were laid for the science called chronobiology (Foster, Kreitzman, 2005).

Until 1980, the effect of light on the biological cycle of various mammals was observed, but it was believed that this could not also happen in human beings. It was erroneously hypothesized that this could have been an evolutionary advantage with respect to other mammals (Perlow *et al.*, 1980). On the contrary, famous research published in the Science Journal has demonstrated that light also affects humans' biological clock (Lewy *et al.*, 1980).

A timed system acts in our organism, managed by the suprachiasmatic nucleus of the brain, which lasts about 24 hours, through which all physiological processes such as sleep, nutrition, hormone production, blood pressure, body temperature, digestion, psychological alertness, coordination and muscle strength are managed (Klein, Moore, Reppert, 1991). It is important to emphasize that all of these factors have a daily cycle of action and also act on the effectiveness of our immune system. To know the actual timing state of our circadian cycle, the most effective method is based on the measurement of the amount of melatonin in the blood (Rosenthal, 1991; Lewy, Cutler, Sack, 1999). Melatonin is a hormone produced by the pineal gland under the control of the suprachiasmatic nucleus. In an individual with a correct timing of the circadian rhythm, melatonin increases in the evening hours immediately after sunset and begins to decrease before sunrise, remaining low during the day. However, the circadian clock needs to be synchronized for the needs of life on Earth, and the exogenous element that generates this synchronism is daylight. Indeed, in the absence of the rhythms of natural light, due to the Earth's rotation, the clock can go out of phase with multiple implications for our health and well-being (Evans, Davidson, 2013).

In the last 30 years, there has been increasing interest in research into the NIF effects of light and color on humans (Küller *et al.*, 2006; CIE, 2015; Westland, Pan, Lee, 2017). NIF has a direct effect on the human central nervous system which affects the brain waves as detected by an EEG (Badia *et al.*, 1991; Noguchi, Sakaguchi, 1999), the subjective alertness (Daurat *et al.*, 1993; Cajochen, 2007; Smolders, de Kort, Cluitmans, 2012) and people's moods (Lewy *et al.*, 1982; Küller *et al.*, 2006). Lighting have also effects on our behavior (Flynn *et al.*, 1973; Baron, Rea, Daniels, 1992) and the working memory (Miyake, Shah, 1999) which is an important element of cognitive psychology for problem-solving skills (Huiberts, Smolders, de Kort, 2016; Okamoto, Nakagawa, 2016) and learning (Mayron *et al.*, 1974; Keis *et al.*, 2014).

These arguments, mainly developed in the research area of chronobiology, have long been ignored in the design field and the lighting industries. The reasons for the lack of planning and production attention are many. On the one hand, there have been more than ten years during which the manufactures were committed to implementing the new technologies of solid state light sources as a primary objective of research and development. On the other hand, there is a lack of demand, concerning this type of design innovation, due to total ignorance of these issues by users and designers.

The interest in research concerning the quality of life indoors has also increased a lot today after the awarding of the Nobel Prize for Physiology or Medicine 2017 to Jeffrey C. Hall, Michael Rosbash, and Michael W. Young for their research that demonstrated molecular and genetic mechanisms that control circadian rhythms (Davis, Sample, 2017).

6.2 The new domestic landscape and the IoT

In recent years, the design of the domestic landscape has seen in the advent of new Internet of Things (IoT) technologies, an element of unprecedented technological innovation, which has very important implications in interior design and well-being of people. This layer of the project, in the new domestic landscape, concerns the design methodologies and technologies available to lighting designers, but also the vast area of makers and all those who operate in the do it yourself (DiY) sphere. Nowadays, makers are independent designers who design and produce for the benefit of themselves, or to sell their custom designs to others (Anderson, 2012). Their design is based on a continuous experimental activity, different from the logic of economy of scale, achieving a new relationship with the project, which often lays its foundations on open source and open project systems that are spreading in the domestic context (openHAB, 2018; Home Assistant, 2021).

In the history of design self-production and DIY has been an established reality for many years, whose importance has gradually expanded over time to various product sectors, including, very recently, thanks to the advent of solid-state lighting, also the lighting sector. With the advent of voice assistants, this trend has accelerated even more in the home environment (Young, Young, 2018). Before LEDs, lighting sources mainly used low voltage (110-230VAC), with the consequence of having to comply with a series of certifications necessary to ensure the electrical and thermal safety of the product that were not within the reach of makers. LEDs, on the other hand, have an extra-low voltage supply (<50VAC and <120VDC) and the electrical certification concerns the LED driver, which takes the mains voltage, transforms it into extra-low voltage and today can also be IoT connected. The LED driver powers the LED sources and becomes part of the project as an already certified device. As stated by Michele De Lucchi (2011) the availability on the light source market of new semi-finished products, such as LED modules and LED strips, now provides lighting designers with fascinating new degrees of freedom in interior lighting design.

In the context of wireless local area networks, the definition of Bluetooth 4.0 in 2009 laid the groundwork for the use of Bluetooth Low Energy (BLE) as a communication medium, through very reliable mesh-type networks, to control systems in the home. The difference with the pre-existing Wi-Fi lies in the lower power consumption of BLE and the limited amount of data that BLE can transmit, which is still adequate for a network that handles control signals. Other recent mesh-like networks similar to BLE are Zigbee and Z-Wave (Tross, 2019). It is in this context that, in recent years, lighting communication and control systems (LMS) born directly in the IoT context have been developed.

In the era of wireless and LEDs, today luminaires can also free themselves from the constraints of the power grid while maintaining the archetypes of home lighting, providing a welcoming mood also in the transition areas between interior and exterior. Such as the innovative MESH lampshade in turned, painted and corrosion-resistant aluminum, equipped with rechargeable batteries, designed by Marco Acerbis for Platek that was used in the indoor/outdoor transition spaces in the Alabriga Home Suites project in Girona.

Fig. 1 – Wireless power supply. MESH lampshade by Marco Acerbis at Alabriga Home Suites, Girona. Archt. Aryanour Djalali. Lighting Design: David Vilà, Espais d'Illuminacio. Photo S. Rotger. Courtesy Platek.

The impact of the IoT on the domestic landscape concerns the home automation themes related to the control of home systems, on which the "smart home" concept of the IoT has been superimposed today. These terms are often used interchangeably although they are not the same thing (Young, Young, 2018). Home automation works independently and should be able to adapt to people's preferences, so it is one of the possible functions of the smart home. In the modern smart home, there is also the possibility of system access interfaces ranging from smartphones to voice assistants, with the ability to easily integrate new devices and control functions from different manufacturers. Home automation always requires a design made by professionals, while the smart home is also part of the DIY to try to create a safe, comfortable, low power consumption and open environment, which is easy to upgrade and reconfigure (Leitner, 2015). In the smart home, the project covers the management of audio-video entertainment systems, temperature, shades, security and all IoT devices in the home, increasingly including artificial lighting.

LMSs have entered residential environments with two different approaches: those existing before the advent of the IoT have adapted, developing devices to interface the IoT. Other newer ones, found in some LED drivers, have integrated directly into the IoT using BLE or Wi-Fi communication networks. In addition, next-generation LMSs, to be truly smart, need fundamental inputs to be able to relate to users and the indoor environment: sensors that detect the presence and location of users and sensors that can determine the amount and color characteristics of the light present in the interior.

Among the pre-existing communication systems, the main communication standard used since the 1990s for general lighting control is the Digital Addressable Lighting Interface (DALI) (IEC, 2018). This system can connect up to 64 devices, such as light sources, but also other devices such as switches, dimmers, sensors of various types and other compatible devices. Initially, the DALI network was only wired but today, through a gateway device, it can also be a wireless BLE and Zigbee. In 2019, the standard was upgraded to D4i, which facilitates the integration of sensors and communication devices, enables correlated color temperature (CCT) and color control, as well as defining new capabilities to store and report diagnostic data to the LMS. The introduction of tunable white LED lighting to the market, along with sensors, enables CCT control of light in interiors.

An example of tunable white lighting design is the renovation of a Victorian townhouse on Powerscroft Road in London's Clapton district. The aim was to adapt it to the needs and tastes of modern living. The lighting design integrates discreetly into the architecture in terms of visual continuity, without imposing itself and at the same time offering a lighting solution that makes it possible to create the ideal environment for various activities and the best atmospheres for different occasions. The result was an environment characterized by a harmonious fusion of Victorian and contemporary architecture, with clear visual and sensory references to the intended use of the different rooms. Tunable white dimmable lighting, with CCT varying between 1,800K and 6,500K, was designed to create the ideal environment for different activities, using Reggiani's Mood and Yori luminaires, connected in a BLE mesh, programmable and controllable via smartphone.

Fig. 2 – An example of tunable white lighting design. Victorian townhouse on Powerscroft Road in London's Clapton district. Lighting design: There's Light. Photo: JJ Greenwood. Courtesy: Reggiani.

For many years, the most widely used system in the broader context of building automation has been the KNX standard (ISO/IEC, 2006), based on a wired network, which makes it possible to manage up to 57,000 different devices in a building. Many manufacturers make KNX-compatible devices that can be easily integrated into the lighting design to control the sensors, the amount and the CCT of light emitted. KNX was created to enable energy savings and comfort in all types of buildings through the Heating, Ventilation, and Air Conditioning (HVAC) control. Recently, gateways have been developed to be able to use KNX also in a Z-Wave wireless network and there are several apps for smartphones, which can act as interfaces, also remotely, for programming, managing and controlling the system.

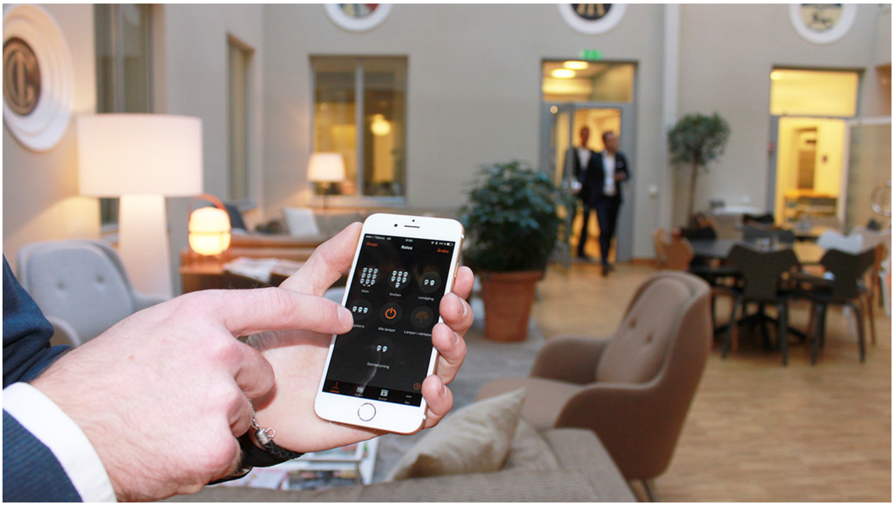

Fig. 3 – The Ratos Headquarter lighting in Stockholm controlled by Casambi App. Courtesy Annell Ljus + Form AB.

In 2011, the BLE mesh based Casambi LMS was introduced on the market. It can also interface with the DALI network. Casambi can configure and control lighting via an app, on a smartphone or tablet, with an intuitive graphical interface, or even via classic wall controls. Using a photo of the environment, the lighting designer can configure the system directly on the image to define the controls, luminaires and sensors, and establish behaviors and links between all devices.

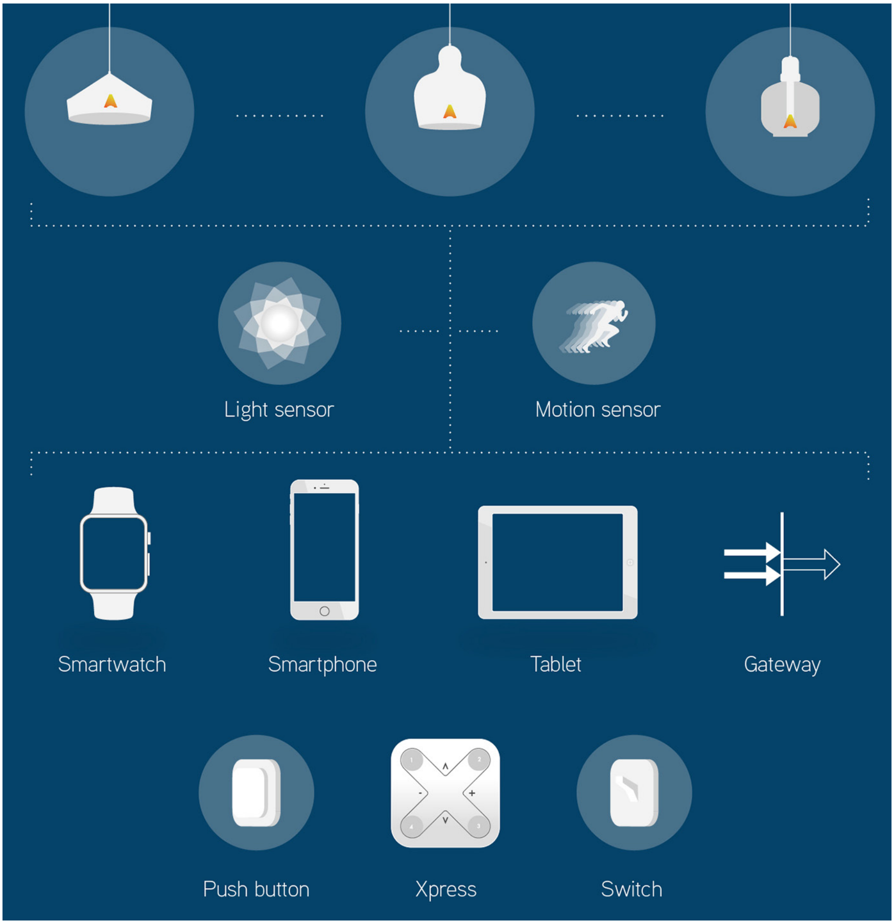

Fig. 4 – The Casambi system. Courtesy Casambi Technologies Oy.

Silvair has also developed a wireless BLE mesh based LMS for managing lighting systems in professional applications, such as retail and office spaces. Fagerhult developed the e-Sense set of systems using Casambi technology. These include a very advanced LMS, the e-Sense Tune, which provides individual users with independent and personal control to tailor lighting to their needs and preferences, even in different workspaces, when, for example, they move between personal offices, individual workspaces in shared areas, or conference rooms and recreational spaces. The idea is that everyone can take their lighting with them. Using light sensors and user recognition, the system is able to adapt the lighting based on the user's profile and choices. User identification may be through recognition of the smartphone, or other smart device, carried by the user. Among the scenarios that can be set in the e-Sense Tune there are those for energy saving and that for the artificial simulation of the dynamic cycle of daylight, with its variation in CCT and quantity, which follows the user during the day, with the aim of encouraging the natural phasing of his/her circadian rhythm.

Fig. 5 – The Artemide App makes it possible to gather information through presence and daylight sensors built-in Artemide lamps. This creates Heat Maps in the App that allows the collection of essential data on the behavior of who interacts with space and allows the setting of lighting control parameters. Courtesy Artemide.

At a higher level, Artemide has developed a dedicated app, the Artemide App. This system enables lighting and color management, as well as user presence detection to intelligently determine the most appropriate lighting for each context. In addition, the app is also a design tool for the lighting designer. Indeed, by importing the plans of the interiors into the app used in the designer mode, it is possible to establish the relationships between the various elements of the smart lighting project and the related behavior. The lighting designer therefore expands his classic scope of intervention, which goes beyond the choice, positioning and orientation of the lighting points, to more complex elements of the project: such as the definition of the behavior of the LMS and the design of changing lighting scenarios, depending on the behavior, the time of day and the natural light conditions actually present in the interior.

6.3 Lighting and well-being in residential environments

With the 2017 Nobel Prize in Medicine awarded to Hall, Rosbash, and Young, the issue of circadian lighting for people's well-being in interiors has been brought to the attention of industry manufacturers and innovation-minded designers (Young, 2017). Indeed, the human body is made to function and synchronize according to the rhythm of the continuous variations of natural light (Czeisler *et al.*, 1981). Our physiology would require us to be exposed to natural light during the day and complete darkness at night, to promote sleep, a fundamental function for health, and to ensure the proper phasing of our circadian rhythm (Wright *et al.*, 2013).

Considering NIF effects, the amount and chromaticity of light in interiors is different than that in exteriors, because it depends on the urban context, the windows (Farley and Veitch, 2001) and the contribution of artificial light (Andersen, Gochenour, Lockley, 2013). Often, in urban areas, optimizing residential interior spaces dramatically reduces the amount of natural light present. Direct sunlight is perceived as too intense and is therefore reduced with the help of blinds, curtains or other anti-glare systems (Reinhart, Voss, 2003). Frequently in interiors, even during the day, regardless of the presence of natural light, artificial light is turned on. Two research studies conducted in residential interiors, in Boston and Milan, have shown that ambient light is not able to properly stimulate the human circadian system (Gochenour, Andersen, 2009; Rossi, 2019a).

Many individuals suffer from delayed sleep phase disorder (DSPD) caused by exposure to inadequate evening light (Cajochen *et al.*, 2011; Green *et al.*, 2017). The social context can also contribute to a form of DSPD known as social jet lag, in which the person is systematically out of sync with social standards that generally involve a morning commitment to work and/or study. This has also been associated with problems such as excess consumption of substances such as caffeine, alcohol and nicotine (Wittmann *et al.*, 2006; Parsons *et al.*, 2015).

The alteration of the circadian rhythm can occur late, called owl disorder, or early, called lark disorder (Phillips, 2009). Over the course of an individual's life, it is quite common for him/her to be more owlish when young, extremely active in the evening but with late morning awakenings, while in old age they become larks, with fatigue just after sunset and early morning awakenings. However, beyond certain limits, these alterations become pathological. An alteration of the normal circadian cycle can cause migraine (van Oosterhout *et al.*, 2018), headache (Pringsheim, 2002), irritability (Evans, Davidson, 2013), seasonal depression (Rosenthal, 2006), immune system deficiencies (Christoffersson *et al.*, 2014), chronic fatigue (Bonsall, Harrington, 2013), obesity and diabetes mellitus (Cedernaes, Schiöth, Benedict, 2015). It has also been hypothesized that there is an increased likelihood of developing certain cancers as a result of the alteration of the circadian cycle that affects the production of various hormones and the efficiency of the immune system (Stevens, Rea, 2001; Schernhammer *et al.*, 2013; Yadav, Verma, Singh, 2017).

Today, circadian lighting is possible thanks to LED and IoT technologies (Rossi, 2019b). This design method should not be considered a complication, but neither can it be simplified. It is inaccurate to say that a lighting product is human centric or circadian, while it is more correct to say that it can have functionalities aimed at achieving a lighting design for the well-being of people in residential environments (Rossi, 2018). The lighting product lays the groundwork for having the technological functionality useful for biodynamic lighting, but this is not enough. It is the design of an interior as a whole, with the LMS being able to create biodynamic lighting able to connect to other key elements of the design, such as the ability to relate to the user, the colors of the interior and the changing availability of natural light.

Circadian artificial lighting needs to be assessed in typical human positions, it depends on the weather, daylight contribution and also the way all elements, such as walls and furniture, affect ambient light. A luminaire designed for these purposes should enable the control of the emitted luminous flux, the CCT, the color, the ratio of direct to indirect emission, should be energy efficient with a long operating life, and have an LED driver that can be controlled remotely within the IoT (Brodrick, 2015). Or at least offer a subset of these functionalities. In addition, the LMS that controls the lighting system must provide the ability to dynamically vary lighting throughout the day, in terms of quantity and CCT, following the pattern of natural light.

It is in this context that the new light sensors (Caicedo, Li, Pandharipande, 2017), presence sensors (Newsham *et al.*, 2015) and the innovative indoor position detection systems (IPS) of users, based on smartphones, actigraphs and BLE beacons (Kalbandhe and Patil, 2016), have also assumed a fundamental importance. Continuously tracking the amount of natural light actually present in an interior is critical to managing its circadian deficiencies in indoor environments. Sensors are also beginning to be offered on the market that are able to determine the CCT of the real ambient light (Valencia, Giraldo, Bonilla, 2013), that is the result of the relationship between natural light, artificial light and light reflected by the colors of the wall surfaces and furnishings present in the interior.

The ability to detect the presence and position of users in the interior allows the LMS to adapt the artificial lighting accordingly, making up for the lack of natural light and following the daily dynamic pattern of the same. These design methodologies are the future of design oriented to the well-being of residential environments and energy saving in the context of the smart home.

6.4 The open question of color

Three key steps are missing for interior design to introduce NIF effects on the human circadian system.

Today there is no European or worldwide standard for quantifying these elements in interior design. The world body that deals with light, color, and the human visual system, the Commission Internationale de l´Eclairage (CIE), has proposed a document in which it takes stock of research in this area (CIE, 2015). Since it is a multidisciplinary issue, there are many entities that are dealing with it in various capacities. The European Commission has published a scientific report recognizing that LEDs for lighting do not present problems for human health and also providing the scientific existence of the relationship between lighting and the human circadian cycle (SCHEER, 2018). In recent years, methods for quantifying circadian lighting have been proposed and two national standards have been defined in Germany (DIN, 2015) and the USA (IES, 2018b), but without giving design guidance. On the building certification side, the Well Building Standard (IWBI, 2014) has been proposed, which focuses on the health and mental and physical well-being of people in buildings. This certification concerns building features that have a direct impact on human health and well-being, and these include circadian lighting, although it is a non-mandatory parameter in evaluating a building's score.

There has also been scientific contention for years over the issue of color rendering of artificial light sources. The current international standard, the CIE's CRI, has been criticized by much research (Davis, Ohno, 2010; Freyssinier and Rea, 2010; Smet *et al.*, 2010; Bodrogi, Brückner, Khanh, 2011) because it doesn't really describe the ability of LED sources to make us see interior colors well. In 2018, a different standard for quantifying color rendering, ANSI/IES TM-30-18, was proposed in the U.S., with a stronger scientific basis (IES, 2018a). However, this has not been accepted by the CIE, so many manufacturers continue to use an inadequate method to describe their LED light sources.

The third element that is missing even more in the evaluation of NIF effects is precisely the color factor that intervenes on the surfaces of interiors and furnishings, i.e., what the eyes of human beings observe when they are awake in the 80-90% of their time they spend indoors. Research on NIF effects for the circadian system was conducted in the laboratory, on human subjects with dilated pupils, and fixed gaze inside a Ganzfeld-type sphere, in which quasi-monochromatic lights were projected (Brainard *et al.*, 2001; Thapan, Arendt, Skene, 2001). Therefore, these experiments lack any contribution from the reflection factors and geometries of everyday surfaces and how they send light back onto the retina. We know very well that, instinctively, people's gaze is almost never directed towards the light sources, but rather towards the surfaces of the environment and the evaluation of the interior space depends not only on the CCT of light, but also on the other natural and colored elements that may be present (Boyce and Cuttle, 1990; Bellia, Pedace, Fragliasso, 2017). It is known that visual perception of color can influence mood and emotion (Ou *et al.*, 2018). Many studies have been done using color samples or computer images with the difficulty of being able to transfer them to the design field (Anter, Billger, 2010), while other studies have been done in the field (Küller *et* *al*., 2006; Hårleman, Werner, Billger, 2007), with differences that may also be cultural in nature (Hogg *et al*., 1979).

Fig. 6 – Shine a Light House, Oberaudorf, Bavaria. Brueckner Architekten – Arch. Michael Brem. Interior design Anthea Herrle. Lighting design: iGuzzini. Photo F. Holzherr. Courtesy Brueckner Architekten.

Fig. 7 – Shine a Light House, the kitchen. Brueckner Architekten – Arch. Michael Brem. Interior design Anthea Herrle. Lighting design: iGuzzini. Photo F. Holzherr. Courtesy Brueckner Architekten.

This complex relationship between natural light, artificial light, and interior colors are present in the Shine a Light residence project (BIM award winner at the Heinze Award 2020) on the outskirts of Oberaudorf, near the Bavarian Alps, by Brueckner Architekten, where there is a dynamic integration of natural and artificial light thanks to the large windows, which also give residents breathtaking views.

The interior color scheme was derived from the impression of the setting sun in the mountains. The cautious cool colors, in various shades of gray, are combined with warm orange accents, creating a perfect interplay between noble and sublime, warm and cozy. A special space is the corner kitchen in the central living room, whose shape is inspired by the Kaiser mountain range. The building is energy self-sufficient thanks to geothermal boreholes and a photovoltaic system. The lighting was created with numerous custom-made elements, which blend unobtrusively into the architecture, and other iconic products in keeping with the building's classic modernity. Most of the lighting products are Laser Blade 5 LED Minimal, Underscore InOut RGB and decorative products from iGuzzini. The lighting is dynamic and has been designed in relation to the colors of the interior, it is also connected with a DALI network in the KNX smart home and enables the control of CCT and also of the color that is sent back from the parts of the interior coatings that have neutral white/grey colors. In this project the chromatic dimension of the interior has been entrusted mainly to the light, both the natural light that enters from the large windows facing south and the artificial light integrated into the architecture and the smart home project.

6.5 Conclusions

The scientific soundness of the human circadian cycle and its proper timing for our health is now an established fact that should make us think about how to design and renovate interiors in the future. Designers have two fundamental tools at their disposal, light and color, which can act on the NIF effects of humans. Today, lighting is designed almost exclusively to meet the needs of the human visual system and energy conservation. The chromatic project, on the other hand, follows canons linked to trends as well as to emotional, cultural, geographical and artistic aspects. The problem is that lighting designers and color designers, who work in interiors, often don't talk to each other and aren't aware of the implications their design can have on people's health. Even worse, lighting is often only included in a final phase of the project.

An argument often made against introducing a new way of designing is that electric lighting in interiors has existed for more than a hundred years, performs its function well for visual perception, and does not generate health problems for users. However, this statement is incorrect. Instead, it should be said that almost no one had, until a few years ago, posed the fundamental question of scientifically analyzing whether the light present in interiors could create problems, mainly when there is a low contribution of natural light. To overcome these obstacles, a holistic approach to interior design would be necessary, which tends to overcome the sectoralization and super-specialization of the professionals involved in the project.

There are indeed nearly no reference standards in this area. However, from the research conducted in the third millennium, we can draw some basic design guidelines for the construction and upgrading of buildings to increase occupants' exposure during the daylight hours to the circadian light par excellence, which is natural light. However, this is often lacking in interiors, and adequate circadian artificial lighting is required, which also depends on the colors of the surfaces, although this involves higher energy consumption. We can define some characteristics that interior lighting must possess to be considered circadian:

- Artificial lighting in interiors should always be dynamic with quantity and CCT varying throughout the day in a similar manner to natural light variations.
- To promote the phasing of the circadian cycle, lighting in the first half of the morning and the first half of the afternoon, should be higher and have a cooler CCT.
- In the relaxation and evening phases we should use a warm CCT, with low levels of lighting, so as not to counteract the normal production of melatonin and not to delay our circadian cycle.
- Today, in the absence of specific standards, to determine whether and how much light reaching the eyes can be circadian, one can

use the reference model proposed by Rea and Figueiro (2016), and calculate it using available software tools (LRC, 2017, 2018; OSRAM SYLVANIA, 2018).
- High color rendering light sources should always be preferred. Actual color rendering should be evaluated using TM-30-18.

As explained in the previous paragraphs, all this is possible only today thanks to the availability of tunable white LED sources, connected in a network and managed by an LMS that is able, through sensors, to detect the presence of people and the quantity and quality of light present in the interior.

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