Color Design & Technology

A Multidisciplinary Approach to Colour

PART 2

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Chapter 1 Light and Color for the Show

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Abstract

The design of light and color to improve the performance of a singer or actor or any artist is of absolute importance. As part of a show, be it a live performance, a movie, or a television program, the designer's choices can make any event unforgettable or sink its quality, invalidating the efforts of all other figures involved in production.

The decisions of the lighting designer (or director of photography) are those that give direction to the production. According to the presented content, these choices provide the aesthetic sense and the narrative path, mediated by experience. Few months may be enough to grasp the theoretical rudiments of the profession. Still, their successful implementation requires a sensitivity and a technical maturity that must be built over the years.

This chapter will focus on specific entertainment sectors, namely the live stage and lighting for television and cinema, the variables and technologies involved, and some elements that differ from the much more well-known architectural lighting field.

The aim is to provide an overview of at least part of what is sometimes defined as a niche sector. In reality, it represents a significant branch of color and lighting design, with varied and fascinating contents that must be known and valorized.

Keywords:

Lighting design, Color design, Entertainment, Live stage, TV lighting, Cinema lighting

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1. Introduction

Perception of color is closely linked with the phenomenon of light, to the point that one could say that the first does not exist without the second. Also, concerning lighting, technology is now at a level, which allows us to use color without any limits or sacrifices.

However, the color concerning architectural lighting still encounters some resistance, from the simplest ones to understand, such as the tendency to avoid cold and not very organic colors for illuminating food, up to a very personal acceptance or rejection of color related to culture and perception of the space innate to each individual. If it is true that light can transform space, reshaping the way it is perceived, the same can be said of colored light.

Different shades of white light (or even colored) have been often used in various lighting contexts in recent years. In the architectural field, luminaires capable of emitting colored light have existed for more than thirty years (an example could be the Metamorfosi line by Artemide in the ‘90s). Today, modern control technologies allow one to effortlessly manage the light intensity at home in terms of tones of white and color (the Philips Hue system, for example).

The domestic environment, however, is not covered by restrictive standards. Talking about the workplaces, in recent years, the use of different color temperatures (white light) is at the base of the techniques called human-centric lighting. This particular approach consists of regulating the circadian rhythm with specific light cycles, helping individuals improve their performance in both day and night shifts.

In interiors, the use of color is mostly accepted. It can be for human-centric lighting purposes or communicative-aesthetic use, enriching the spaces with hints of color to make them more attractive.

In the field of exteriors, however, the matter is more complicated. Concerning architectural spaces, colored lighting is often used to give a new look to buildings (which may not be particularly interesting during the day); it is also true that this tendency generally works well for the most contemporary architecture.

If we talk about historical facades, it is widespread to face a certain resistance to the use of colored light. The interpretation of architecture (which should be one of the primary objectives when lighting historical buildings) can be easily distorted using colors with nothing to do with the historical context.

There are numerous lighting cases of historical buildings that have received such harsh criticism from experts and the people that they have been

removed to be replaced by more “sober” and respectful lighting. The situation gets more acceptable if colored lighting is only temporary and has a specific purpose (for example, pink lighting of monuments for the fight against breast cancer day). Another field in which color is welcome is that of temporary art installations, for which there are many festivals around the world. Summing up, it is easy to draw a parallel between colored light and the spectacularization of spaces.
For this reason, of the various lighting areas, the more oriented on the use of color are those related to the entertainment. To present an example, in this chapter, we will discuss lighting features for live stage, television, and cinema.

2. Live stage

The incredible influence of lighting when an event is staged has been known since the days of classical theater. Still, the advent of electricity made it possible to bring the impact of light to levels never reached before. A striking example of the use of electric light in a scenic context of propaganda was the well-known “Cathedral of light.” In 1934, at the Zeppelintribune in Nuremberg on the occasion of the Reichsparteitag (the annual meeting of the Nazi party), Albert Speer, Hitler’s trusted architect, used 152 searchlights with a diameter of 150 cm, loaned by the Luftwaffe to outline the frame of the immense stadium capable of host over 340.000 people. The effect obtained left the ambassadors of other states astonished (Speer *et al.*, 1997), and the joint use of Richard Wagner’s music (Die Meistersinger von Nürnberg) was what consecrated the power expressed in that event (Moller, 1980). More than the political content of the parade, it was the synaesthesia between light and sound that forged the message of hegemonic power that would soon become sadly known to the whole world.
Later, the introduction of color in lighting in entertainment events is already documented in the postwar period in British theaters (Applebee, 1950). It even hypothesizes using these experiences to evaluate the quantity and chromaticity of light for the commoners (Strange and Hewitt, 1956).
The study of the relationship between illumination and stage in show events intensifies until it is finally formalized in 1970 (Reid, 1970).
Time passed, and technology evolved, and in 1980 the moving lights were introduced to the market by Vari-Lite (Vari-Lite, 2021). The use of color becomes more and more important in live performances, until, in 1988, the concerts of The Wall by Pink Floyd, designed by Mark Brickman, traced a milestone for the lighting of shows (Williams, 1988).

Since then, technology has made great strides in live performance, and manufacturers have incredibly evolved the luminaires from those that were once used in the ’80s in discos. However, numerous issues must be taken into consideration.

2.1 The variables

Lighting design for the live stage is not a simple task. Thinking of it as a series of operations that lead to a result, it could be possible to compare it to an artistic or architectural activity. Despite the freedom granted to the designer, numerous factors make the lights’ preparation for a live show an actual race against time; there are many steps and checks to do in a short amount of time.

First, the show venues are usually available only a few days before the show itself, so it is impossible to plan ahead. This situation is also due to the high rental costs of these structures. The production operations concentrate on the dates near the show, and lighting is only a part of things to be done. Designers are faced with the need to prepare and test everything in few days (a little more if the show production is of considerable size). Working experience is essential in these cases; beyond the ability to find optimal solutions to possible unforeseen events, knowing the various venues where the shows are held (pros and cons) is a big help for the lighting designer. Software tools such as Wysiwyg (CAST, 2021), Deepence[2] (Syncronorm, 2021), L8-Software (L8 Ltd., 2021), and Spotlight (Vectorworks, 2021) can somehow help to simulate the lighting installation. Still, as regards their use, there are different opinions on the part of professionals. Some avoid these systems entirely; others use them in the early phase, while others use them more widely. These are mainly software packages that allow the professional to virtually rebuild the stage (possibly starting from the CAD drawings of the set designers) and virtually install existing light projectors, simulating the control consoles. It is also possible to export files that allow a certain level of automation during the actual show. However, the algorithms used by these digital tools are not always very refined. Sometimes, the simulated show does not have enough correspondence with the result, to the point that some designers prefer to avoid the digital simulation and rely only on experience.

Everything is decided in the last few days. The lighting designer’s artistic sensibility remains the essential tool; knowing how to read the show’s various nuisances and visually transpose them, improving their emotional charge.

In addition to the venue's timing and the architectural characteristics, there are other external variables to consider. When stages are outdoors, the concert usually begins while the sun has not yet entirely set. Therefore, the luminous envelope evolves throughout the show, and it is necessary to tweak artificial lights to adapt to the transition. These changes in the natural light atmosphere's color depend on numerous factors; place, season, time, and weather conditions. These are almost always variables that can be evaluated only at the last moment due to their very nature.
Another element that can significantly influence the Lighting Designer's color choices is the light deriving from other technical equipment: the now constant presence of LED-wall elements that put in scene digital content not created directly by the lighting designer.

Figure 1. The presence of natural light (when working outdoors) and other light elements such as LED walls are parameters that must be taken into consideration when designing the lighting for a live show. Image courtesy: Giovanni Pinna.

In addition to external factors and production variables, typical elements of the show's usual creation have to be considered. Even just the type of

engagement of the lighting designer (a contract with the production or directly with the artist) can affect the professional's freedom of choice.
Then there are the other figures in the show; the most important is undoubtedly the artist himself, who can have a personal vision of the show's color that ultimately can affect the designer's decisions.
These requests may not be persistent, but they can happen; in this case, the designer must mediate them with his vision of the show.
Another critical factor is the Set Designer. The physical construction of space (geometries, materials, choice of colors) is crucial for lighting choices, and the maximum synergy between the two teams is more than desirable.

2.2 Possible choices

A common approach is that the project starts to form in the designer's mind early, a "painting without colors" that gives more importance to the scene's compartments, the spotlights' orientation, and the fillings done with wash-type lights and so on. In this phase, the use of color is only a draft; it is possible to get an idea of what colors could be used, but the information available is still not enough, and by going more in-depth, the risk is to waste your work. When everything goes into production, at the time of staging, it is possible to really give color to the event; work upwards, and observe the "substance." It might also happen that the initial ideas might be rejected during the programming phase because they do not fit the rest of the scenic machine (which perhaps remains unknown until just before the show).
The choice of colors is almost always the result of a personal interpretation. Beyond the sporadic requests that might happen, it is the designer who chooses, through his musicality. The lighting designer can almost be considered an added musician who participates using time, measurements, and lyrical writing on every track on cue. It is essential to know the programmed repertoire entirely to build its chromaticity, passing from framework to framework. The freedom to do all this then depends on the factors seen before and on the luminaires available and the designer's competence to use them (acquired only through experience).
Entering into the heart of the choice of colors, the approaches that can be adopted are practically infinite and mostly depend on the lighting designer's sensibility. One can play on warm tones on warm, cold on cold, complementary colors, and in contrast, what is essential is that these choices accompany the concert narrative.
The chromatic shift marks the passage from one module of the show to another. Often authors like to create narrative compartments composed of

multiple songs. A good choice is to keep the same colors within these segments, introducing different colors to move to the next compartment.

Figure 2. Color is often used to characterize specific narrative arcs in shows. Image courtesy: Claypaky. Photo Credit: Ralph Larmann.

The presence of natural light in the concert's initial moments can be an issue, partly because of its intensity and partly because of the variability of its appearance. A possible approach to this problematic condition can be neutral white light, assisted by the correct quantity of artificial smoke, which gives an impression of diffuse glow, "naturally" luminous. Achromatic light can be used while waiting for the sun to set completely and then introduce the first color. However, it should be emphasized that the transition from achromatic to colored light creates a notable detachment, which should be reflected in the show's narrative. It implies a change of state even in the spectators, who find themselves more immersed in it.

2.3 Technology

In addition to natural light, variability comes from digital contents that are usually presented through LED walls or projections, as already mentioned. Nowadays, the amount of light emitted by these devices is by no means

negligible, and their presence is now a must in the productions of a certain level.
Spanning from simple vertical elements that can change the perception of depth on the set to actual modules scattered all over the stage, their amount of light and coloring must be considered when placing the other luminaires. It’s always a good thing when the lighting designer coordinates his work with the digital content creator to create synergy and manageable choices. This interaction can be significantly improved using a technology called “media server,” which allows the integration of video content in the control consoles operated by the lighting staff, ensuring a good mixing level. Usually, however, the lighting designer (when he cannot make suggestions about the colors of the videos) must adapt to digital content to make harmonious light choices.
Technology continues to improve in years, providing more possibilities every day: higher powers, more control, and bright “full” colors. However, the flip side of the coin is that as the possibilities increase, so does the complexity.
If we think of the shows of just some years ago, everything was about using fixed beacons and colored gel filters; flexibility was less, but the preparation time was lower.

Figure 3. A modern moving light produced by Claypaky (an Osram business). The HY B-EYE K25, in addition to the typical features of motorized luminaires, allows the control of every single LED, allowing countless kaleidoscopic projections.

Moving lights allow an extensive range of colors to be obtained, gobos to be implemented, light to be profiled (to remote control them), and multiplied with prisms, as each luminaire is potentially able to carry out the work of many. Then there are video projections, sets in transparency, special materials, platforms, etc. Technology increased flexibility to a level that that was unthinkable until not long ago, but such improvements can be overwhelming for the designer. The possibility of obtaining unlimited colors does not necessarily mean that this should be done. At times, using a fixed spotlight with a colored gel filter is still the most effective and economical choice, even if less blatant.

This consideration does not mean that technology should be avoided. On the contrary, today, more than ever, it is essential that professionals are prepared for the possibilities that products and systems have to offer, always keeping up to date to evaluate the best choices.

Concerning advanced light sources, in the entertainment field, solid-state lighting has conquered its position. Although their dominance is not as established as in the architectural lighting field, the possibility to contain the power implied has LED manufacturers develop many devices that mount this type of lamp.

However, from a chromatic point of view, the LED still encounters resistances; some purists of gas discharge light sources prefer to avoid LEDs, opting for classic lamps, assisted by dichroic or even gel filters.

Regarding hues, LED light sources can produce more saturated colors, not in terms of the color rendition of illuminated materials, but the light beam's appearance, when projected into the environment where artificial smoke is dispersed. In terms of entertainment, the color white remains a weak point of LEDs, making it less brilliant than the one created with metal halide lamps. Some LED sources are offered in RGBW format (Red, Green, Blue, and White) to give greater chromatic flexibility, but the result is still not comparable with discharge lamps from a white point of view. The same is true for sources that must provide a portion of UV for fluorescence, such as Congo-blue, for which traditional lamps are still more appropriate.

The digital light sources are more flexible from a control point of view, but as mentioned above, too much flexibility can extend the show's preparation time.

3. TV and Cinema

Lighting for television and cinema has a very ancient history. The use of artificial light in indoor studios instead of outdoor theaters (around the '20s) led to a revolution of light in scenography, giving the great masters of photography a whole new ground in which to experiment. One of the most notable masterpieces that made this experiment the key to his success was Fritz Lang's Metropolis. In this movie, light assumes a semiotic value, in the management of light and shadow, in the dynamic projections, using electric discharges and luminous objects as scenographic communication tools to amplify the scenes' affect human emotions (Roth, 1978). Lang drew his inspirations from Art Deco, Bauhaus, and Futurism (Rutsky, 1993; Wolfe, 2020), applying them to light.

On that occasion, the design of light went from a scientific and technological subject to a communicative, scenographic expression (Pooky, 2016).

The first and foremost difference between TV and cinema lighting is that the illumination must meet the requirements for the cameras and not for the human observer (Box, 2020). Even if sophisticated, these devices do not have the typical processes of the visual system (such as the color constancy or the lateral inhibition of the retina, to name just a couple). Some technologies may attempt to copy some visual system features; however, the complexity of human perception cannot be easily replicated, and some corrections are necessary.

Concerning color, the immediate attention that the lighting group (usually composed of the director of photography and the gaffer) must have is to apply all the necessary technical procedures to balance the color temperature of all the sources on stage. It is fundamental to carry these procedures following the white balance for digital cameras or stock of film chosen.

A second fundamental task consists of introducing colored light for aesthetic reasons or simulating specific light sources in the scene to support the program's narrative.

3.1 Color temperature and white balance

I do not intend to dwell on the basic concepts of color science, as it is not the purpose of this chapter. Still, speaking of the world of cinema and television lighting, we can report that some importance is given to the CIE chromaticity diagram of 1931 (Smith and Guild, 1931). This diagram represents the gamut of human visual perception. The colors all appear in their most saturated version on the outside of the horseshoe. Of these colors, the most peculiar ones lie on the line of the purples, which represents colors that are obtainable only through the mixing of the others (the extremes of the visible spectrum in particular). The most interesting component, however, is the one given by the central space of the diagram. That is where the color saturation decreases until it reaches the curve known as the "Planckian locus," which represents the whites in their various shades (or make-up, as is often said in this field), namely the color temperatures.

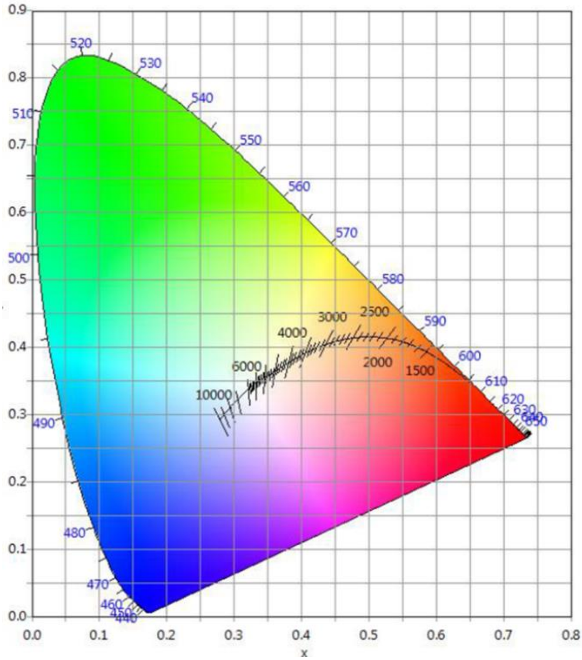

Figure 4. The CIE 1931 color space.

Warm light to cold light, commonly measured in Kelvin, is well known and widely used in workplaces' lighting (the base of Circadian lighting). Still, the problem linked to this aspect, in the TV-lighting field, is considered from a different point of view. When lighting sources with multiple color temperatures are present simultaneously in an environment, the human visual system tends to mitigate the dominant colors by attenuating the perception of different colors; the light will appear warmer or colder but still white. This phenomenon does not apply to equipment such as cameras. Whether they are film stock or digital sensors (both Charge-Coupled Device and Complementary Metal-Oxide-Semiconductor), they are not equipped with the sophisticated correction methods typical of the human visual system. They might have attenuation algorithms, but they will never be at the level of our visual perception. Stock films, for example, are balanced at 3200 K (Tungsten light) or 5600 K (Daylight); digital cameras, on the other hand, can be set to a value of your choice between 3200 K and 5600 K, but always and in any case only one color temperature at the time. This means that when there are whites with different color temperatures simultaneously in a scene, the camera can only have a single white point as a reference; the others whites will all appear more or less yellowish or bluish.

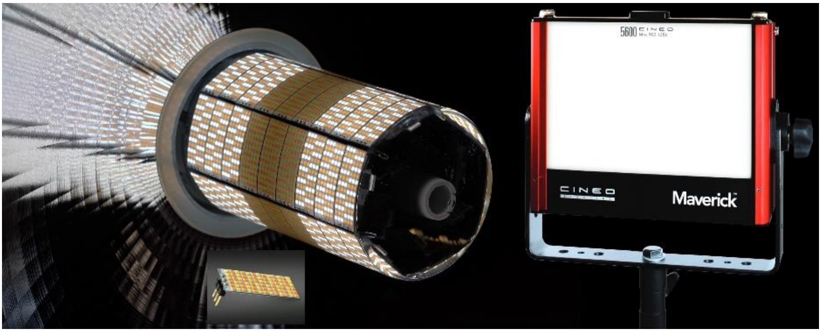

Figure 5. Example of luminaire that can change the tone of white. On the left, a detail of the Reflex, which is equipped with LED chips with different color temperatures. On the right, the Maverick allows changing the white by switching the front panel treated with different phosphors coating to achieve different color temperatures. Image courtesy: Cineo Lighting.

This situation is not acceptable when it comes to television recordings, and therefore, once the reference white has been established, some correction operations on the sources must be adopted. On non-dynamic light sources, it is possible to operate additively by summing other sources with different color temperatures to balance. Alternatively, it is possible to use subtraction, reducing the power of some components of the spectrum. This result is usually obtained (at least partially) employing correction filters (gels) named CTO (Color Temperature Orange) or CTB (Color Temperature Blue). Filters have different intensity levels (full, half, quarter, one-eight) and are designed to shift the hue of light along with the Planckian location. LED light sources can modify the shade of white (but also colored) light with multi-chip sources (which would enable an additive synthesis of different LED dies) or luminaires with interchangeable phosphor panels. However, it is not uncommon to use filters even on solid-state sources; "traditional" lighting designers sometimes use this technique in specific fields such as the exhibition area (Murano, 2017).

3.2 KELVIN or MIRED units

When correcting the whites with gel filters, the result is not linear. Suppose one uses a 1/8 CTO filter on a cold source. In that case, it can get a color temperature shift of about 200 K. If it applies the same filter on a warmer light source, the shift can even reach 600 K. The amount of radiation that is filtered is also very different. The color temperature corrections applied via hardware on LED lighting fixtures follow what was set by the operator. However, a consolidated methodology deriving from gel filters has resulted in a particular approach to color temperature corrections.

To not be constrained by the lack of linearity described above, filter manufacturers consider units called MIREDs (Micro REciprocal Degree) instead of using the simple Kelvin scale (Priest, 1933). The MIREDs then also entered the interfaces of the control systems of LED luminaires; although not strictly necessary, they provide a more comprehensive selection range that considers the technician's preferences. The MIREDs are calculated by dividing 1 million by the color temperature to be converted; therefore, a MIRED shift is obtained by subtracting the starting value from the target one. For example, a daylight type source (6500K) is equal to about 154 MIRED. In order to convert it to an incandescent type warm light source (3200K / about 312 MIRED), a shift of 158 MIRED is required (obtainable with a full CTO gel). On the other side, the quantity of radiation lost in the process (this obviously does not apply to LED) is not considered here.

3.3 Δuv or Green/Magenta axis

The Planckian locus is the curve describing the different color temperatures in a chromaticity diagram. However, the correlated color temperature data alone (Davis, 1931) is not sufficient to explain the chromatic make-up of lighting sources, especially when it comes to the rendering of a scene through a camera. The isotherm lines that transversely intercept the Planckian locus curve represent the chromatic variability that sources with the same color temperature can have. Numerically, their value is commonly described by the parameter Δuv (MacAdam, 1937) that quantifies the distance of a point on the isotherm from the Planckian locus (which ideally represents a "pure" white). If the value is positive (above the curve), white will be tinged with green/yellow; if the value is negative (under the curve), white will be tinged with magenta/pink. Therefore, it is possible to have

whites with the same color temperature (expressed in K) and still have different colors.
Instead of the Δuv, in TV Lighting, the green-magenta axis describes these displacements above or below the Planckian locus. Also, in this case, chromatic correction filters are available to tweak the chromaticity of the light. These filters act on what is known as the CC scale (Color Compensation Scale) and can range from Full minus green (magenta filter, 30M) to Full plus green (green filter, 30 G). As seen for the MIRED, this terminology (the magenta-green axis) has also been adopted in the most recent luminaires, whose LED chips are equipped with green and magenta dies to correct the chromaticity of whites according to the CC scale and implemented in the product interface.
The correction given by the green and magenta LEDs is particularly crucial in luminaires that have two or more chips inside them that produce different white lights through conversion with phosphors. This type of LED has dies that emit blue light through a layer of phosphors, which reconvert the colored light into white light, whose characteristics vary according to the composition of the phosphor layer. Thanks to this technology, it is possible to have lighting fixtures that implement colored light (Red, Green, and Blue) and white light with two different color temperatures; for example, cold (daylight at 6500 K) and warm (tungsten at 3200 K). However, when these latter two sources are used to obtain intermediate color temperatures, it is possible to run into some problems. The transition from cold light to warm light can be done by mixing the two and corresponds to a linear shift on the chromaticity diagram. The Planckian locus, however, is not a line but a curve. The intermediate shades of light between hot and cold fall under the Planckian curve, thus tending towards magenta. In modern LED lighting fixtures, however, thanks to green and magenta LED chips installed in the products, it is possible to compensate for this issue with control systems by adjusting the position of the light on the green/magenta axis.

3.4 New technologies, new problems

Solid-state light sources have now also taken root in the entertainment lighting sector. The efficiency of these sources is undoubtedly a plus for anyone; however, one of the main reasons why LED technology is particularly desirable (now that the emitted fluxes have become more than reliable) is the possibility of controlling numerous parameters of every single luminaire remotely. Indeed, some aspects will take some time to be accepted, such as comparing LED with high-power HMI sources; the latter are more available and less expensive for the same luminous flux. Still talking about economic aspects, the productions are often reluctant to invest in something that provides (in the end) the same visual achievement that was obtained with “classic” sources, looking only at the final result and not at man/hours and better management control processes. Finally, the irruption of electronics in a field historically dominated by electrical engineering leads to the need for staff improvement, introducing skills that were not widespread before; this requires a lengthy training process that often slows down production in a sector where timing is essential. In addition to the difficulties described above, there are other aspects to take into consideration. The advent of LEDs has enriched the color palettes of directors of photography. Numerous ways of standardizing color coordinates have been studied to have a common vocabulary. However, this made it even more evident that different cameras capture color in a slightly different way from each other. In addition to this, the reproduction of captured colors is done on devices (the user TV screens) that often have inadequate gamuts. The light color can be created by adding different types of LEDs or by conversion using phosphors. In order to complicate things, these two approaches can include several methodologies and other elements. In the various steps necessary for video reproduction, metameric matches can frequently happen that, with the “classic” sources were less common. In some aspects of the production, a high color rendering is desirable: make-up, wardrobe, brand identity, commercial products, logos. Their reproduction must not be distorted by light sources that are inadequate from a spectral point of view. Numerous efforts have been made to find a way to describe the ability of a light source to render color; the color rendering indexes have existed for several years. However, they present some fundamental problems that make them unsuitable for the television and cinema lighting sector.

3.5 CRI and “classic” color rendering indexes

The most common method of determining the color rendering of a light source is to use it on specific sample colors and evaluate how much it differs in rendering these samples compared to a reference source. Comparison is the method underlying the CRI (Color Rendering Index) proposed by the CIE. Around the mid-1900s, the advent of fluorescent sources and their early way of rendering colors raised the need to invent a method for determining the chromatic quality of sources. The CIE proposed a test sample method of color rendering evaluation. Today, the CRI is still in force, in its updated and extended version, but it presents numerous issues that cause continuous criticism and requests for revision (Davis and

Ohno, 2009). First of all, the system is based on 14 color samples taken from the Munsell color system (Munsell, 1905). The first choice of these samples (eight) was made up of low saturated colors and only in a second version were those with higher saturation added. However, the choice of colors does not adapt to discontinuous spectrum light sources (like metal halides or LEDs) and can give very low render values even for very performing sources. In addition to this, there are various inconsistencies, like the choice of color space used to calculate the chromatic distance between the points (CIEUVW), the use of the Von Kries transform for color adaptation (defined as inadequate), the lack of continuity at color temperatures above 5000K for which one passes from the Planckian locus to the CIE Daylight locus (CIE, 1999), and many other criticisms.

These issues have led some researchers at the National Institute of Standards and Technology (NIST) to develop an alternative system known as Color Quality Scale (Davis and Ohno, 2010). The CQS is based on the evaluation of Munsell color samples (like for the CRI) that are much more saturated. Moreover, the color space used is CIELAB (more uniform than CIEUVW). In this way, the sources are not penalized (nor rewarded) if they increase the chroma (a factor considered positive for contrast perception (Hashimoto and Nayatani, 1994)) compared to the reference, but only if they reduce it and if they cause changes in hue or reduction of lightness. A further and more recent color rendering index is ANSI/IES TM-30-20 (IESNA, 2020), which uses an objective statistical method to evaluate the differences between the test source and the reference source set of 99 samples. The color space used is CIECAM02 (CIE, 2004). The evaluation of fidelity is not only taken into consideration, but the standard also implements a graph that shows a comparison between the two gamuts (test and reference), which give a straightforward and quick reading of the results obtained. Without debating on which index is the most appropriate, there is one thing in common: all these indexes have been designed for the evaluation of color rendering by the human visual system. However, in the television and cinema lighting sector, the final observer is the camera and not the human being. This crucial difference makes all classic color rendering indexes inadequate for television and cinema purposes. It was, therefore, necessary to study specific indexes for this sector.

3.6 TLCI-2012, TLFM-2013, and SSI indexes

In an attempt to remove the well-known problems of the CRI, the researchers of the European Broadcasting Union (EBU), based on some preliminary studies (Sproson and Taylor, 1971), developed two indexes for the television sector, the Television Lighting Consistency Index in 2012 and the Television Luminaire Matching Factor in 2013 (European Broadcasting Union, 2017).

TLCI-2012 removes the human observer regarding color discrimination, entrusting the evaluation to a spectroradiometric measurement of a sample (the first 18 patches of the Macbeth ColorChecker, excluded the greyscale) compared with a reference sample. The chromaticity of the reference used can be on the Planckian locus (if the test source is below 3400 K), on the Daylight locus (if above 5000 K), or a linear interpolation between the two (if the test is between 3400 and 5000 K). The measured values are then processed by a specific software that simulates the typical characteristics of the cameras and displays where the image will be played. For cameras, the considered parameters are responsivity curves, linear matrix, and optoelectronic transfer function or gamma-correction. As for the displays, instead, the parameters are the non-linearity or electro-optical transfer function, the chromaticities of the set of primaries, and the white balance point. Once the calculations have been performed, the software returns a unique value (Qa) from 0 to 100, which indicates how feasible it is to attempt a chromatic correction on the source. The results must be interpreted according to the type of production; for example, film-type shots have a much more restrictive reading than live shots with different cameras.

The TLMF-2013 is very similar to the previous one. The main difference is that instead of an ideal reference source, a real one is used, which can be chosen according to the type of test source and specified in the results. The aim is to be more direct than TLCI in the evaluation of the mix between different sources. While TLCI is helpful for equipment manufacturers, TLFM is aimed at practitioners to predict a combination of sources before arriving in the studio, where it is usually too late to intervene (Wood, 2013).

A further index is the Spectral Similarity Index (SSI), developed in 2016 by experts from the Academy of Motion Picture Arts and Sciences (Academy of Motion Picture Arts and Sciences, 2020). In the SSI, to avoid the excess of variability given by the human evaluation or numerous and different cameras (which may have spectral sensitivities that reach out of the visible spectrum), the variance of the test source related to the reference source is taken into account. Therefore, the spectral sensitivities of the various devices are not considered, but instead, how much (in certain regions of the spectrum) the test source spectrum differs from that of the reference source (Tungsten or Daylight). The purpose was to create a so-called “confidence factor.” The result is an index (0 to 100) on the probabilities of the test source to render the colors in the same way as the reference.

4. Conclusions

In this chapter, some lighting sectors in which color plays a fundamental role were presented. Typical problems and some possible solutions were also presented. In these fields, solutions usually do not derive from scientific practice but rather from the experience of the professionals involved. At present, it is not yet conceivable that automatic processes can replace the specialized figures of technicians in this sector, even if some studies in this direction are already underway (Hsiao, Chen and Lee, 2017). The artistic nuances of the entertainment world (which also include theatrical lighting, musicals, and fashion shows) are so varied that even those who have an adequate skill set (for example, architectural lighting designers) may not be able to deal with show projects on a professional level, without first having accumulated sufficient experience. The subject matter is the same, from a physical point of view (and within certain limits also technological). Still (as described in the chapter), the approach is significantly different, as are the terminologies and tools.

This does not mean that there is a discriminating factor to boast the title of lighting designer (freely used both in the entertainment world and in the world of "traditional" lighting). Still, due attention must be paid to the differences that characterize the various sectors, approaching novelty with an open mind to better understand various professional sectors. Overlaps, technologies involved, tools used, final goals to be pursued, and the means to achieve them. Being able to understand the design approaches of the various professional fields could allow tackling every project (the lighting of buildings, shows, installations but also retail, workplaces, etc.) drawing inspiration from multiple sectors, to obtain a final result which technically adequate, but also able to inspire those who experience it.

5. Conflict of interest declaration

The author declares that nothing has affected his objectivity or independence in the production of this work. Neither the author nor his immediate family member has any financial interest in the people, topics, or companies involved in this article. Neither the author nor his immediate family member had a professional relationship with the people and companies cited in this article. The author also declares that no conflict of interest, including financial, personal, or other relationship with other people and organization within three years of beginning the submitted work that could inappropriately influence, or be perceived to influence, this work.

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References

Academy of Motion Picture Arts and Sciences (2020) ‘Academy Spectral Similarity Index (SSI): Overview’. Academy of Motion Picture Arts and Sciences. Available at: https://www.oscars.org/sites/oscars/files/ssi_overview_2020-03-13.pdf (Accessed: 4 May 2021).

Applebee, L. G. (1950) ‘Stage Lighting in the Post-War Theatre in Great Britain’, *Lighting Research and Technology,* 15(8 IEStrans), pp. 265–284. doi: 10.1177/147715355001500801.

Box, H. C. (2020) *Set lighting technician’s handbook: film lighting equipment, practice, and electrical distribution*. Fifth edition. London ; New York: Routledge/Taylor & Francis Group.

CAST (2021) *wysiwyg Lighting Design - CAST Group of Companies Inc.*, *CAST Software*. Available at: https://cast-soft.com/wysiwyg-lighting-design/ (Accessed: 4 May 2021).

CIE (1999) *A method for assessing the quality of daylight simulators for colorimetry*. Paris: Bureau central de la CIE.

CIE (ed.) (2004) *A colour appearance model for colour management systems: CIEAMO2*. Vienna, Austria: CIE Central Bureau (Technical report, CIE 159:2004).

Davis, R. (1931) ‘A correlated color temperature for illuminants’, *Bureau of Standards Journal of Research*, 7(4), p. 659. doi: 10.6028/jres.007.039.

Davis, W. and Ohno, Y. (2009) 'Approaches to color rendering measurement', *Journal of Modern Optics*, 56(13), pp. 1412–1419. doi: 10.1080/09500340903023733.

Davis, W. and Ohno, Y. (2010) 'Color quality scale', *Optical Engineering*, 49(3), p. 033602. doi: 10.1117/1.3360335.

European Broadcasting Union (2017) *EBU TECH 3355 - Method for the Assessment of the colorimetric properties of Luminaires*. Available at: https://tech.ebu.ch/publications/tech3355 (Accessed: 4 May 2021).

Hashimoto, K. and Nayatani, Y. (1994) 'Visual clarity and feeling of contrast', *Color Research & Application*, 19(3), pp. 171–185. doi: 10.1002/col.5080190305.

Hsiao, S.-W., Chen, S.-K. and Lee, C.-H. (2017) 'Methodology for stage lighting control based on music emotions', *Information Sciences*, 412–413, pp. 14–35. doi: 10.1016/j.ins.2017.05.026.

IESNA (2020) 'IES Method for Evaluating Light Source Color Rendition – ANSI/IES TM-30-20'. Available at: https://store.ies.org/product/tm-30-20-ies-method-for-evaluating-light-source-color-rendition/ (Accessed: 4 May 2021).

L8 Ltd. (2021) *L8 software, L8 LLC*. Available at: https://l8.ltd/m/ (Accessed: 4 May 2021).

MacAdam, D. L. (1937) 'Projective Transformations of I. C. I. Color Specifications', *JOSA*, 27(8), pp. 294–299. doi: 10.1364/JOSA.27.000294.

Moller, L. E. (1980) 'Music in Germany During the Third Reich: The Use of Music for Propaganda', *Music Educators Journal*, 67(3), pp. 40–44. doi: 10.2307/3400616.

Munsell, A. H. (1905) *A Color Notation*. G. H. Ellis Co. Available at: http://archive.org/details/acolornotation00munsgoog (Accessed: 24 September 2020).

Murano, F. (2017) *L'illuminazione delle opere nelle mostre d'arte*. Maggioli Editore. Available at: https://books.google.it/books?id=CpmhswEACAAJ.

Pooky (2016) 'Industrial meets art deco – How Metropolis helped design the future', *Light and shade,* 3 April. Available at: https://www.pooky.com/2016/03/03/industrial-meets-art-deco-how-metropolis-helped-design-the-future (Accessed: 4 May 2021).

Priest, I. G. (1933) 'A Proposed Scale for Use in Specifying the Chromaticity of Incandescent Illuminants and Various Phases of Daylight*', *JOSA*, 23(2), pp. 41–45. doi: 10.1364/JOSA.23.000041.

Reid, F. (1970) 'Techniques of stage lighting', *Lighting Research & Technology*, 2(3), pp. 125–134. doi: 10.1177/14771535700020030701.

Roth, L. (1978) '"Metropolis", The Lights Fantastic: Semiotic Analysis of Lighting Codes in Relation to Character and Theme', *Literature/Film Quarterly*, 6(4), pp. 342–346.

Rutsky, R. L. (1993) 'The Mediation of Technology and Gender: Metropolis, Nazism, Modernism', *New German Critique*, (60), p. 3. doi: 10.2307/488664.

Smith, T. and Guild, J. (1931) 'The C.I.E. colorimetric standards and their use', *Transactions of the Optical Society*, 33(3), pp. 73–134. doi: 10.1088/1475-4878/33/3/301.

Speer, A. *et al.* (1997) *Inside the Third Reich: memoirs*. New York: Touchstone.

Sproson, W. N. and Taylor, E. W. (1971) 'A color television illuminant consistency index, BBC research department report 1971-45'. BBC. Available at: http://downloads.bbc.co.uk/rd/pubs/reports/1971-45.pdf (Accessed: 4 May 2021).

Strange, J. W. and Hewitt, H. (1956) 'Light and Colour in Daily Life', *Lighting Research and Technology*, 21(10 IEStrans), pp. 255–276. doi: 10.1177/147715355602101001.

Syncronorm (2021) *DEPENCE2. Syncronorm GmbH.* Available at: https://www.syncronorm.com/products/depence2/overview/ (Accessed: 4 May 2021).

Vari-Lite (2021) *Vari-Lite*, *Vari-Lite*. Available at: https://www.vari-lite.com/global (Accessed: 4 May 2021).

Vectorworks (2021) *Entertainment & Lighting - Design Software | Vectorworks Spotlight*. Available at: https://www.vectorworks.net/en-GB/spotlight (Accessed: 4 May 2021).

Williams, M. (1988) *Pink Floyd and Company - Interview to Marc Brickman*, *Pink Floyd and Company*. Available at: https://pfco.neptunepinkfloyd.co.uk/band/interviews/other/other_frame.html (Accessed: 4 May 2021).

Wolfe, S. (2020) 'Fritz Lang's Metropolis. How the Iconic Silent Film Took Inspiration from Art Movements', *Artland Magazine*, 11 December. Available at: https://magazine.artland.com/fritz-langs-metropolis-how-the-iconic-silent-film-took-inspiration-from-art-movements/ (Accessed: 4 May 2021).

Wood, M. (2013) 'Television Lighting Consistency Index – TLCI'. Mike Wood - Contact Information. Available at: https://www.mikewoodconsulting.com/articles/Protocol%20Fall%202013%20-%20TLCI.pdf (Accessed: 4 May 2021).