A design approach to lighting and colour rendering in indoor sets

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Indoor lighting and colour design practice for television and movie industries evolved in the decades with the assumption that the real-time observer is the camera instead of the human being. Nevertheless, even modern cameras do not have the human visual system's dynamic, adaptation, and cognitive correction. Although technology evolutions of cameras allow regulatory actions to control colour parameters, there are still open issues in this sector. Solid-State lighting has dramatically enriched the colour creativity for directors of photography, and numerous ways of standardising colour coordinates have been proposed to have a common vocabulary. However, this has also led to the rise of new technical and organisational issues. Different cameras capture colours illuminated by LED sources, slightly different from each other. This paper aims not to cover the scientific aspects of the lighting of indoor sets but to collect some of the information relating to the operations design on light and its chromaticity under a design method approach.

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Introduction

Nowadays, lighting technology is at a level that allows us to use colour without limits or sacrifices. If it's true that colour concerning architectural lighting still encounters some resistance, it is also true that coloured light can transform space, reshaping the way it is perceived. Of the various lighting fields, the more oriented on the use of colour are those related to entertainment such as television and cinema. Even with some significant overlap, the approach to lighting for television and cinema differs a lot from the more general architectural lighting. There are many differences in the tools and technologies used, the organisation of the workgroup, the design process, the objectives to be expressed with lighting and the strategies to achieve them, and most of all, the colour control of the illuminated set. A common approach is that the project starts to form in the designer's mind early, a "painting without colours" that gives more importance to the scene's compartments, the spotlights' orientation, and the fillings created with wash-type lights. In this phase, colour is generally only a draft; it is possible to get an idea of what colours could be used, but the information available to the designer is still not enough. When everything goes into production, at the time of staging, it is possible to really give colour to the event; work upwards, and observe the "substance".

Lighting for indoor sets has a one-century history. The use of artificial light in indoor studios instead of outdoor theatres around 1920 led to a revolution of light in scenography, giving the great masters of photography a whole new ground to experiment. Fritz Lang's Metropolis was one of the most notable masterpieces that made this experiment the key to his success. In this movie, light assumes a semiotic value. In managing light and shadow, in the dynamic projections, electric discharges and luminous objects are used as scenographic communication tools to amplify the scenes' affect human emotions [1]. Lang drew his inspirations from Art Deco, Bauhaus, and Futurism [2-3], applying them to light. From scientific and technological subject, lighting design evolved into a communicative, scenographic expression [4]. The emotional influence of lighting when an event is staged has been known since the days of classical theatre. 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, Albert Speer used 152 searchlights with a diameter of 150 cm, loaned by the Luftwaffe to outline the frame of the immense stadium capable of hosting over 340.000 people. The effect obtained left the ambassadors of other states astonished [5], and the combined use of Richard Wagner's music was what consecrated the power expressed in that event [6]. More than the political content of the parade, the synesthesia between light and sound forged the message of hegemonic power that would soon become sadly known to the whole world. Later, the introduction of colour in lighting in entertainment events is already documented in the postwar period in British theatres [7]. These experiences were even used to hypothesise and evaluate the quantity and chromaticity of light for the commoners [8]. The study of the relationship between illumination and stage show intensifies until Reid finally formalises it in 1970 [9]. Time passed, and technology evolved. In 1980 the moving lights were introduced to the market by Vari-Lite [10]. The use of colour became more and more important in live performances until, in 1988, the concert of "The Wall" by Pink Floyd, designed by Mark Brickman, traced a milestone for the lighting of shows [11]. 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, some issues must be taken into consideration for colour rendering.

Lighting and colour

The first and foremost difference between sets lighting and general lighting is that the illumination must meet the requirements for the cameras and not for the human observer [12]. Even if sophisticated, these devices do not have the typical processes of the visual system, such as colour constancy. Some technologies may attempt to mimic some visual system features; however, the complexity of human perception cannot be easily replicated, and some corrections are necessary.

Concerning colour, the immediate attention that the lighting teams, usually composed of the director of photography and the gaffer, must have is to apply all the necessary technical procedures to balance the colour 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.

Another fundamental task involves introducing coloured light for aesthetic reasons or simulating specific light sources to support the narrative and the set design. The choice of colours is almost always the result of personal interpretation to meet the expectations of the director and set designer. In entertainment, it is also important to know the soundtrack to build its chromaticity, passing from framework to framework. The freedom to do all this depends on the factors already discussed, the available luminaires, and the designer's competence to use them. Concerning the choice of colours, the approaches adopted are practically infinite and mostly depend on the designer's sensibility. For example, one can play on warm tones on warm, cold on cold, complementary colours, and in contrast, essential is that these choices accompany the show's narrative. Another element that can significantly influence the Lighting Designer's colour choices is the light deriving from other technical equipment like LED walls, which put in scene digital contents, or daylight in case of shooting in exteriors.

Nowadays, CCT control, tunable white, is known and used in general lighting. In the TV-lighting field, this aspect is considered from a different point of view. When lighting sources with multiple CCT are present simultaneously in an environment, the human visual system (HVS) tends to mitigate the dominant colours by attenuating the perception of different tones; the light will appear warmer or colder but still white. This HVS phenomenon does not apply to equipment such as cameras. They might have attenuation algorithms, but they will never be at the level of our HSV. This means that when there are whites with different colour temperatures simultaneously in a scene, the camera can only have a single white point as a reference; the other whites will appear more or less yellowish or bluish. This situation is generally not acceptable for video 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 colour temperatures to balance. Alternatively, it is possible to use subtraction, reducing the power of some spectrum components. This result is usually achieved with gels correction filters like the CTO (Colour Temperature Orange) or CTB (Colour Temperature Blue). Filters have different intensity levels (like full, half, quarter, one-eight) and are designed to shift the hue of light along with the Planckian locus. LED light sources can modify the shade of white and coloured light with multi-chip sources or luminaires with interchangeable phosphor panels. However, it is not uncommon to use filters even on solid-state sources; lighting designers sometimes use this technique in specific areas such as the exhibition [13]. When correcting light with gel filters, though, the result is not linear. Using a 1/8 CTO filter on a cold source can get a colour temperature shift of about 200K. By applying the same filter on a warmer light source, the shift can even reach 600K. The colour temperature corrections applied via hardware on LED luminaires follow what was set by the operator. However, a consolidated methodology deriving from gel filters has resulted in a particular approach to colour temperature corrections. To not be constrained by the lack of linearity described above, filter manufacturers consider units called MIREDs (Micro REciprocal Degree) instead of the CCT scale [14]. 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 one million by the colour 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) equals about 154 MIRED. In order to convert it to an incandescent type warm light source, a shift of 158 MIRED is required, obtainable with a full CTO gel filter.

Colour rendering issues

The most common method of determining the colour rendering of a light source is to use it on specific sample colours and evaluate how much it differs in rendering these samples compared to a reference source. Around the mid-1900s, the advent of fluorescent sources and their early way of rendering colours raised the need to invent a method for determining the chromatic quality of light sources. The CIE proposed a comparison method of colour rendering evaluation, the CRI (Colour Rendering Index). Today, the CRI presents numerous issues that cause criticism and requests for revision [15-16]. For example, the system is based only on eight colour samples of low saturated colours taken from the Munsell atlas. However, these eight colours are not suited to discontinuous spectrum light sources, like metal halides or LEDs.

Alternative methods have been proposed to determine the colour rendering. Judd [17] and Thornton [18] proposed subjective preference criteria for colours. Smet *et al.* [19] have proposed a method based on psychophysical tests of visual similarity based on chromatic memory. Bodrogi, Brückner and Khanh [20] method is based on psychophysical tests regarding the perception of the difference of seventeen colour samples, illuminated with both the test and the reference sources. The CQS index proposed by Davis and Ohno [21] is based on fifteen colour samples with high saturation and uses a mathematical method different from the CRI. The method proposed by Hashimoto *et al.* [22] considers that a light source that increases the saturation of the objects, or an increase in the ability of colour discrimination, has a positive impact on the perception of colour quality. The same principle is used in Freyssinier and Rea's method [23], in which a colour gamut index is proposed alongside the CRI. The TM-30-20 [24] is a more recent colour rendering index, which uses a colour gamut and a colour fidelity index. Without debating on which index is the most appropriate, there is one thing in common: all these indexes have been designed to evaluate colour rendering by the HVS. However, in the indoor sets, the observer is the camera. This crucial difference makes all classic colour rendering indexes inadequate for television and cinema. It was, therefore, necessary to study specific indexes for this sector.

In an attempt to remove the well-known problems of the CRI, the European Broadcasting Union (EBU), based on some preliminary studies [25], developed two indexes for the television sector [26], the Television Lighting Consistency Index (TLCI-2012) and the Television Luminaire Matching Factor in (TLMF-2013). TLCI-2012 removes the human observer regarding colour discrimination, entrusting the evaluation to spectroradiometric measurement samples, the first eighteen patches of the Macbeth ColorChecker (excluded the greyscale), compared with a reference sample. The chromaticity of the reference source used can be on the Planckian locus if the test source is below 3400K, the daylight is above 5000K, or a linear interpolation between the two if the test light source is between 3400K and 5000K. 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. The considered parameters are responsivity curves, linear matrix, and optoelectronic transfer function or gamma-correction for cameras. As for the displays, instead, the parameters are the non-linearity or electro-optical transfer function, the chromaticity's 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. Of course, 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 evaluating 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 on the set, where it is usually too late to intervene [27].

A further index is the Spectral Similarity Index (SSI), developed in 2016 by experts from the Academy of Motion Picture Arts and Sciences [28]. 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. Instead, it is evaluated how much the test source spectrum differs from that of the reference source: tungsten incandescent or daylight in some areas of the spectrum. The purpose was to create a so-called "confidence factor". The result is an index (0-100) on the probabilities of the test source to render colours the same way as the reference.

Conclusions

Solid-state light sources have now taken root in the entertainment lighting sector too. The efficiency of these sources is undoubtedly a plus for anyone. However, one of the main reasons LED technology is particularly desirable 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 LEDs with high-power HMI sources. The latter are more available and less expensive for the same luminous flux. Still concerning economical aspects, the productions are often reluctant to invest in something that provides the same visual achievement obtained with traditional 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 consider. The advent of LEDs has enriched the colour palettes of directors of photography. Numerous ways of standardising colour coordinates have been studied to have a common vocabulary. However, this made it even more evident that different cameras capture colour in a slightly different way from each other. In addition to this, the reproduction of captured colours is done on devices, the user TV screens, that often have inadequate colour gamuts. The light colour can be created by adding different types of LEDs or by conversion with 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 that were less common with the traditional sources can frequently happen. In some aspects of the production, a high colour 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 colour; the colour rendering indexes of general lighting have existed for several years. However, they present some fundamental problems that make them unsuitable for television and cinema lighting.

In these fields, solutions usually do not derive from a scientific approach but rather from the experience of the professionals involved. At present, it is not yet conceivable that automatic processes can replace the specialised figures of technicians, even if some studies in this direction are already underway [29]. Moreover, the artistic nuances of the entertainment world are so varied that even those who have a good skill set, such as architectural lighting designers, may not deal with show projects on a professional level without first having accumulated experience.

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