Considerations for planning coloured lighting

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ABSTRACT
The planning of colour lighting differs from planning achromatic lighting in various ways. Applying the same rule therefore cannot provide the kind of certainty simply because our visual perception reacts differently on white light than colour light. When applying white light, it is established practice to estimate brightness by measuring the luminance. However for chromatic light colourfulness and hue also need to be considered. When planners use computer renderings to illustrate their lighting effect that includes chromatic light, another layer of challenge appears. To get the correct colour representation for chromatic illumination that accurately matches the real situation is cumbersome and requires quiet specific knowledge. The purpose of this paper is to point out the misconception that the same rules applys to calculating both white and chromatic light, and to identify a strategy to improve colour accuracy for computer renderings.
Keywords: Environmental Psychology, Lighting Design, Visual Perception

1. INTRODUCTION
Over the years we have witnessed a steady increase of the use of colour lighting on architectural structures. The widespread application of chromatic illumination is an attribute to the rapid development of Light Emitting Diodes (LEDs) for lighting. A considerable number of projects demonstrated that, due to the lack of knowledge and experience in colour lighting application, illuminated structures are either barely visible or stand out to an unwanted degree. Our observation revealed that some of these shortcomings are the results from lack of knowldege in colour lighting calculation. The first aspect to point out is the brightness perception of colour light – the same set of rule in calculating the quantity (brightness) of white light is insufficient in estimating the brightness preception of color light. The second concern we deal with is the differences in representation of chromatic light in computer renderings and in real life. Failure in achieving accurate predictions potentially introduces deviating expectations that may lead to low satisfaction with the solution realized.

2. LUMINANCE IS A POOR PREDICTOR FOR PERCEIVED BRIGHTNESS

For achromatic (white light) conditions, measured luminance is generally considered as an appropriate indicator for perceived brightness. However, when it comes to chromatic lighting, experience tells us differently. In the case of blue LED illumination, lower luminance level provides higher brightness than if it were white light. There could be at least two different reasons that cause such behaviour. The first reason bases on the fact that the eye sensitivity curve defined by the CIE in 1924 underestimated contributions from blue light shorter wavelength. More recent definitions of the luminous efficiency functions have corrected this known shortcoming [1] but are by far not as wide spread as the CIE definition from 1924.

Another reason lies in perceived brightness of chromatic light is insufficiently estimated by its luminance. To determine brightness more accurately, chromaticity characteristics of the stimuli needs to be considered. In general higher colourfulness requires lower luminance and vice versa. Wyszecki and Stiles [2] summarized the result of several studies of heterochromatic brightness matching and found consistently that luminance requirement depends on hue and colourfulness. For application of colour light this means that illuminance levels required to achieve equal perceived brightness needs to be much higher using e.g. amber LED instead of blue. Hence also by mixing blue and yellow light to achromatic light requires more yellow than blue light. The exact relations among colours of different hues and colourfulness levels are not easy to determine. Nevertheless, a rough estimation that is valid for more saturated colors can be derived from the weights which are used to calculate CIE luminance for CRT Displays. ITU-R BT.709 [3] defines those weights with 0.21 for red, 0.72 for green and 0.07 for blue. Hence, luminance that provides an equal brightness for red is three times, and for green, ten times higher than for blue. A similar relationship was found for measurement of how conspicuous chromatic patches appear visually. Blue, in this case, required the lowest luminance levels for an equal level of conspicuity [4]. For the application of colour light this means that spectral composition or, chromaticity coordinates, need to be known to determine correlates of perceived brightness or conspicuity.

3. ACCURATE COLORURS IN COMPUTER RENDERINGS

Computer renderings are indispensable means in presenting ideas and designs in the lighting industry of today. The quality of the lighting simulation provides an indication of how the suggested design looks like when realized. For this reason, the accuracy of color in lighting simulation is critical as it needs to communicate a clear picture of the suggested lighting effect to stakeholders. To achieve accurate colour representations on the display is not always easy. Decisions need to be taken on which aspects eventually to compromise. The saturation of LEDs often falls outside the saturation level that can be rendered by displays. In case of a CRT, the use ed phosphors limit the gamut where as for LCD screens, it is the backlight source (either Cold Cathode Fluorescent Lamps or LEDs) where rendering of saturated color is limited. The simplest way to simulate a red light source would be to represent it by the RGB triple values 255, 0, 0. This indicates a a good result as the dominant wavelength of the red source equals that of the red primary used in the display. The problem and the solution to model colours accurately can be illustrated with the help of the chromaticity diagram. Fig. 1 is a version of a chromaticity diagram that is considered as perceptually uniform. The dashed triangle represents therein the subset of colours that can be rendered by a display device. In the shown case the triangle represents the gamut of a CRT with ITU-R BT.709 [3] reference primaries. A problematic situation appears as lights need to be rendered that lies outside of the triangle. The doted polygon in the diagram shows the gamut of a spotlight that is equipped with red, green, blue, amber and cyan LEDs.

The much larger gamut indicates that many colours cannot accurately be rendered on the BT.709 display. To demonstrate how we can use a geometric procedure to achieve a good representation of chromatic lights that lie outside the gamut we use the example of a cyan LED. First we draw a line from the achromatic point to the point representing the chromaticity of our cyan LED. Than we extend this line towards the outline of the chromaticity diagram. This point represents a pure monochromatic cyan light with a dominant wavelength close to 500nm. As we move along the line towards the white point, all points represent colours with approximately the same hue, but are less and less colourful as the amount of white light increases. The used whitepoint with a correlated colour temperature of 6500K is typical for today's displays. The point where the drawn line (cyan dashed) intersects with the gamut border of the used display (small triangle) gives the chromaticity characteristics of the colour to be used for a accurate representation on the display. For our example the resulting RGB triple values are 0,255,70. This method prioritizes hue accurateness over colourfulness. This is just logical as in general the choice of e.g. a red colour instead of an orange-red colour dominates discussions and colourfulness is therein in general of minor interest. To match colours of chromatic lights with that of other chromatic lights or surface colours is an even more challenging task than representing the colour of

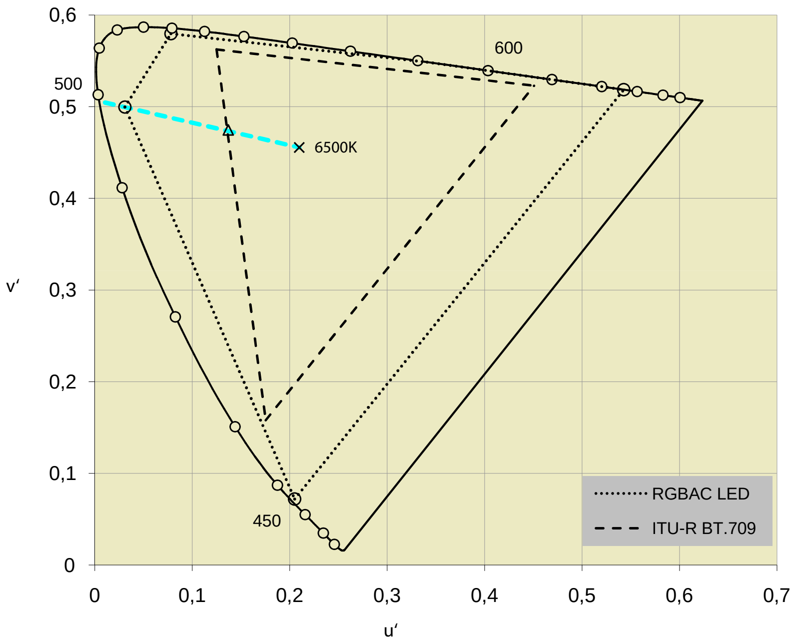

Fig.1
Chromaticity diagram u'v' with gamut of BT.709 phosphors and RGBAC LED sources

a chosen chromatic light. The best way to determine the match is by doing a test setup on location. This is not always possible and for those circumstances the colours can be matched by their chromaticity coordinates. Matching the colours visually on a display unit should be avoided as accuracy is generally too low. While deviations for achromatic and low chromatic colours might be acceptable, those for highly colourful light are not, and it gives results that are unreliable.

4. CONCLUSIONS

The use of chromatic light provides new challenges for light planning. The basic differences in perception of white and chromatic light urge us to reconsider the existing procedures that were developed to plan achromatic lighting. The hereby described concerns and suggested methods are able to assist planners to determine brightness, conspicuity and colour representation of chromatic lighting in more accurate way. The proposed methods help to overcome systematic hurdles for planning chromatic lights and therewith enable designers and planners to focus on their main task namely to bring out the meaning and essence of the subject.

REFERENCES

1. CIE, 170-1:2006: Fundamental *Chromaticity Diagram with Physiological Axes - Part 1*, 2006.
2. Wyszecki, G. and W.S. Stiles, Color *science : concepts and methods, quantitative data, and formulae*. Wiley classics library , John Wiley & Sons, New York, 2000.
3. ITU-R Recommendation BT.709, *Basic Parameter Values for the HDTV Standard for the Studio and for International Programme Exchange*, Geneva, Switzerland, 1990.
4. Reisinger, M., I. Vogels, and I. Heynderickx, “Conspicuity of chromatic light from LED spotlights“, *Colour: Design & Creativity*, No. 6, 2010.