Yellow-free zone series (2018-19)

Experiments with white light and colour-perception

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Abstract

The "Yellow-free zone" (YFZ) series are artistic installations that use artificial light to produce uncanny experiences of colour-perception. YFZ are based on a special lighting system that modifies the colour of coloured objects, in particular of yellow objects. The result is a zone where a white light seems to turn us blind to yellow, as if a digital colour filter was applied to reality itself, questioning the everyday character of our perceptions. I will focus my presentation on the light technology that has been used for developing the "special cold-white" luminaires of the project: dual-band, spectrally tuned “white” phosphor-converted LEDs.

Keywords*: art, light, colour rendition, colour perception, public space*

1. Introduction

This paper presents the "Yellow-free zone" (YFZ) series of artistic installations made in 2018-2019 in Belgium and The Netherlands. Based on a special lighting system, YFZ modify the appearance of some coloured objects using an artificial white illumination. In the current versions of the system, yellow objects are the most affected. After a explaining the basic concept, the research background, and before a subjective description of the experience of the artwork, my presentation will focus on the technological aspects of the light sources that radically transform the visual appearance of yellow objects.

2. General concept

The chromaticity and the colour-rendering are two independent parameters of a white light source. Projected on a perfectly white screen, two white lights – e.g. sunlight and an artificial light – can look identical despite their difference in terms of spectral power distribution (SPD). Different SPDs suggest that these two lights will, however, render “coloured objects” (i.e. objects having a non-flat reflectance curve: usually not white, not grey, nor black) differently. But how different? In an artistic context, the YZF series explores this question with uncanny and counter-intuitive visual experiences, where the colour of objects changes while the light’s whiteness remains stable, giving to the visitors the impression that a digital colour filter was applied to reality itself.

3. Background of the research

I became aware of the possibility to synthesize white light with two monochromatic lights in 2016. Such white lights modify the appearance of some coloured objects and leave intact the colour of achromatic ones. My first prototype was produced in collaboration with a lighting company. It was emitting a warm-white light by the combination of cyan and red LEDs. The colour temperature of 3000K matched the appearance of a halogen lamp. Leaving unchanged white objects, its light transformed the colour of a blond beer into the colour of rosé wine. In 2018, to overcome some limitations, I designed new luminaires from scratch. The SCW-60 luminaires (Special cold-white 60-Watt, Cf. Figure 3), were produced in-house using tailor-made Cyan LED strips and a system of Red remote phosphors. After having presented the SCW-60 luminaires in a solo exhibition at LMNO Gallery in Brussels, BE (Cf. Figure 1), YFZ has been installed in the metro station "Maashaven" in Rotterdam, NL, in 2018 (Cf. Figure 8). “Yellow zone/yellow-free zone”, a second, more complex version of YFZ, was exhibited in 2019 at the Whitehouse Gym project space in Lovenjoel (Cf. Figure 9).

Figure 1 “A White Room Without Yellow”, LMNO Gallery (Brussels), 2018. Special luminaires illuminate a room where 28 samples of paint are displayed on a wall. A second, identical set is displayed in an adjacent room where they appear with their usual colour.

4. Producing a white light with two coloured lights

“White light” is perceived by an observer as being colourless. When a white light is projected on a white diffusor, the diffusor appears white. The spectrum of a white light always contains multiple bands of wavelengths and at least two. Different spectral power distributions (SPD) can produce identical-looking white lights. In colorimetry, a white light is characterized by its colour temperature, measured in Kelvin (K), ranging between 1000 K or 1500 K and ∞. According to this scale, there are multiple shades of white light with different colour temperatures. On a diagram of chromaticity, white lights are represented as points situated on, or very near, the curve formed by the chromaticity coordinates of the lights emitted by a theoretical blackbody, in the range of temperatures already mentioned (this curve is called the “Planckian locus”). I will consider that white light is any light represented by a point on, or very near, the locus. Compared to another one, a white light can appear red, orange, yellowish or bluish, but when a single white light illuminates a scene, the visual system of an observer adapts itself to it and this light will be perceived as colourless, achromatic or “white”.

“Coloured light”, on the contrary, is perceived as being coloured. A white diffusor is coloured when a coloured light is projected onto it. The spectrum of a coloured light contains one or several band(s) of wavelengths, but I will only refer to single-band (i.e. “monochromatic”) coloured lights in this paper. Humans perceive coloured light as having a hue and a saturation. Colorimetry characterizes coloured lights by their chromaticity coordinates or by their dominant wavelength and colorimetric purity.

“Complementary coloured lights” are pairs of coloured lights that, when added together in certain proportions, produce a white light as defined above. Obviously, a pair of coloured lights are only complementary in reference to a single shade of white light. Colorimetry can be used to test mathematically the complementarity of a pair of coloured lights, to calculate the proportions of the coloured lights to be added in order to obtain a white light or to find which shade of white light is produced by this addition.

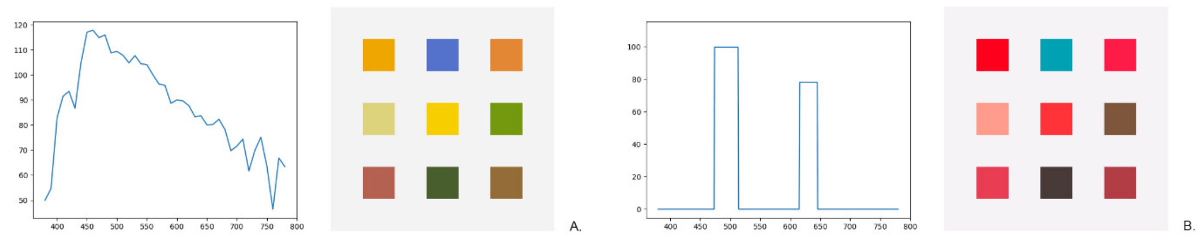

Figure 2 Virtual comparison of the colour rendering of two ideal white lights having the same visual appearance and colour temperature. 9 paints are placed on a piece of white paper (the materials represented were measured with a spectrophotometer). Notice that all colours change but the appearance of the background (white paper). (A - left) CIE standard illuminant D65 (B - right) dual-band white light made of cyan and red complementary lights.

Producing such a special white light is of interest for me because it modifies the appearance of some coloured objects but leaves intact the colour of achromatic ones, a counter-intuitive effect that I use in my art installations to give to the visitors the impression that a digital colour filter is applied to reality itself.

5. Technological requirements

Technological choices are driven by several and sometimes contradictory constraints. For instance, when a dual-band white light is produced by adding monochromatic cyan and red lights, its luminous efficacy, compared to a conventional white light, is reduced because of the missing green component of the light spectrum – the most efficient part of the light spectrum in terms of luminous efficacy. To illuminate a space, the number of luminaires should, in comparison with a conventional LED white light system, be multiplied by 2, 3 or even more, impacting the production and the exploitation costs. Other constraints are the limitations of currently available monochromatic LEDs in terms of wavelengths bands and spectral bandwidths. In order to maximize the effect on the colours, the bandwidth of the monochromatic LEDs should be minimized and for the light to appear perfectly white, the band of wavelengths should be carefully chosen. These adjustments are not always technically feasible with current technology. The optical design of a dual-band light system is another challenge. To obtain a uniform white light, reduced hue shifts at low angles and no coloured fringes around the shadows of illuminated objects, the monochromatic components need to be perfectly mixed together. Finally, LEDs in operation produce heat that requires dissipation in order to assure stability of the light spectrum (on which the whiteness of the light depends), stability of the light output and to increase the lifespan for the overall system.

6. Characteristics of the SCW-60 luminaires

Four versions of the "Special cold-white 60-Watt" luminaire have been developed so far: Alpha, Beta, Version 1 and Alpha with additional reflectors. All have in common a 30 × 30 × 1000 mm aluminium body and a primary light-emission system made of tailor-made, high-power LED strip emitting monochromatic cyan light with a dominant wavelength of 485 nm. Alpha and Beta use the same red remote phosphor, made of 4 mm float glass coated with a silicon-nitride phosphor having a wide range of excitation wavelengths and a peak emission at 645 nm, encapsulated in an ethyl-methacrylate copolymer. Version 1, designed for the public space, uses a slightly different phosphor with a peak emission at 630 nm, coated on an 8 mm polycarbonate sheet for safety reasons. The more orange phosphor slightly decreased the special effect of the light, but it increased the luminous efficacy by 30%. It was anyway necessary because the polycarbonate has a band of light absorption between 650 and 700 nm (Cf. Figure 3) blocking some of the light produced by the other red phosphor.

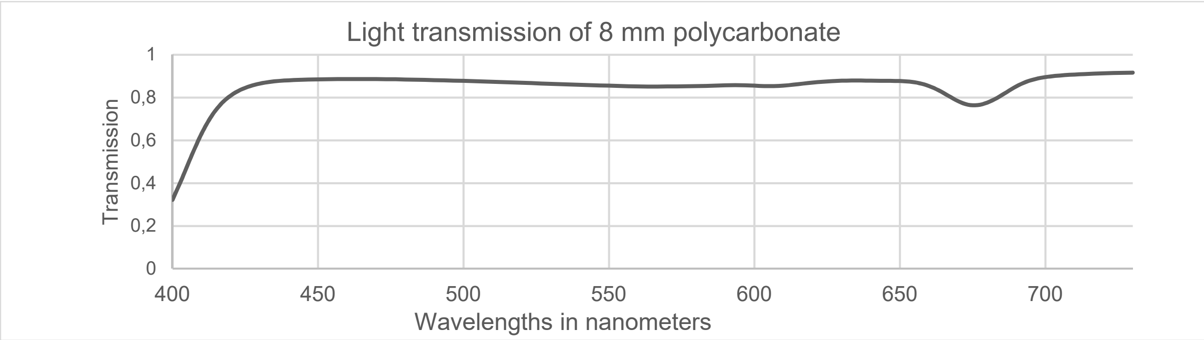

Figure 3 The light transmission of polycarbonate presents a small but significant band of absorption between 650 and 700 nm.

Figure 4 SCW-60 Version 1 (2018), luminaire made of an aluminium body, cyan LED strips and a red-orange remote phosphor coated on transparent polycarbonate.

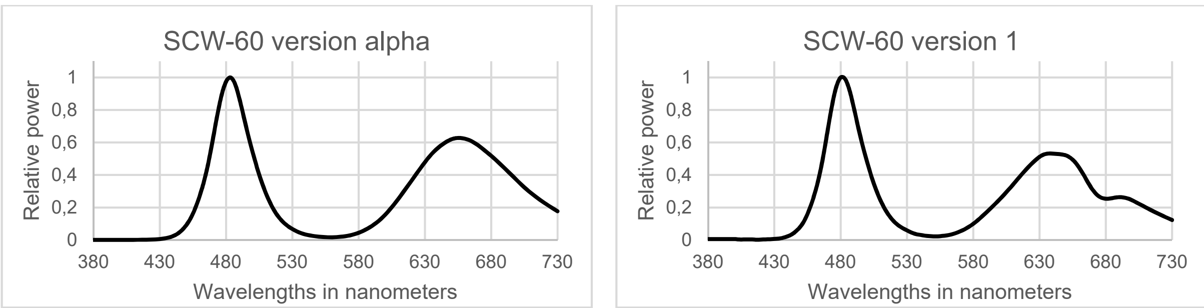

Figure 5 Comparison of the SPD of two versions of the SCW-60 luminaire. The effect of colour modification of the version alpha is slightly stronger because less amber light is emitted around 580 nm, but the version 1 performs 30% better in terms of luminous efficacy. Notice the irregular shape of the SPD on the right, due to light absorption by the polycarbonate near 680 nm.

The choice of a phosphor-converted system presented several design advantages. 300 meters of tailor-made cyan LED strip were manufactured in China at the prototyping stage. The best option that came up was a monochromatic light with a dominant wavelength of 485 nm, slightly too short to be a perfect complementary of a red light that would produce a white light with a colour temperature of 6500 K (490 nm or 495 nm would have been ideal). In this context, ordering a dual-channel LED strip with individual cyan and red LED chips was a riskier and non-spectrally-adjustable option. Half of the coloured LEDs would likely never be used at full power because of the necessary colour adjustment and such a solution requires a secondary optical system for blending the coloured lights. With a cyan primary light source and a secondary remote phosphor, colour adjustments can be performed at the phosphor level, the system can be lit at full power and the remote phosphor acts as an optical blender for the primary cyan and the secondary red lights. To produce the remote phosphors, I designed a semi-automatic coating machine that uses a metallic frame applicator to coat a wet layer of phosphor-resin dispersion, with a thickness of 200 μ, on mineral or organic glass plates.

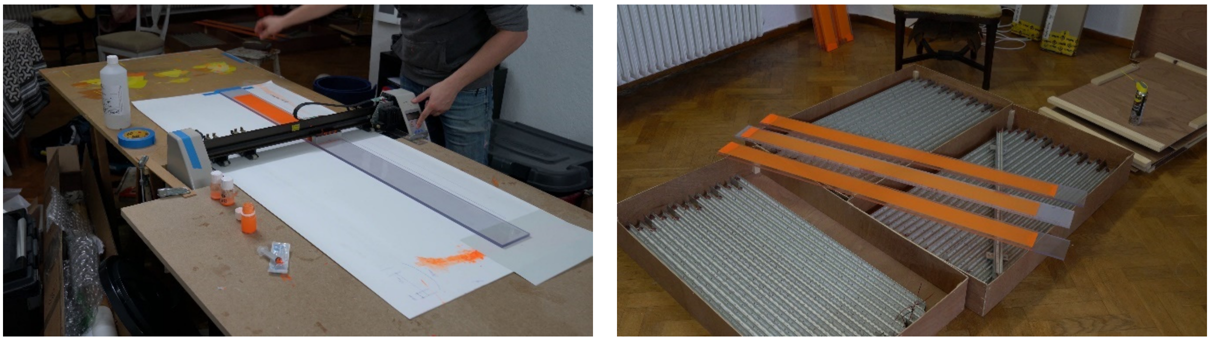

Figure 6 “In-house production/production maison” (2018), screen captures of a short film documenting the production of the luminaires. (Left) the semi-automatic coating machine in action on a polycarbonate plate. (Right) 3 coated plates.

7. Experiencing Yellow-free zone

The experience of YFZ is well described by the following interrogations: “Has a colour filter been applied to reality itself?”, “Am I becoming colour-blind?”, or: “Something is different, but I am not sure what has changed, is it the light?”. Because the special white light is white and because the colours of white, grey and black objects are left unchanged, the experience of YFZ is instantly uncanny, puzzling, counterintuitive. It can feel like magic. After a first moment of surprise, a period of exploration can start: what colours have changed? How do objects that I know look like here? Different people have different clothes, skin pigmentation, eye colours. Some yellow objects become beige, other yellow objects become pink or bright reddish orange. Many blue eyes become turquoise, but not all blue eyes. Indigo becomes cyan and violet, Bordeaux. Some so-called “white” human skins are pink, some so-called “black” skins turn redder, while others are unchanged. If food is there, it can look brighter as if it were dyed with fluorescent brighteners, or, like green salad, almost grey and quite weird. A blond beer becomes pink like rosé wine, another one dark pink like Tavel rosé wine. Light, greenish white wines look identical to colourless transparent water. Some visitors are just happy, some are trying to understand, asking questions about the mechanism. People are getting confused when they see that the digital camera of their smartphone does not records the colour of the light as they see it: “my smartphone sees pink light when I see white light, who is right: me or the camera?”

Figure 7 Pictures of the same scene illuminated by 965 fluorescent tubes (left) and SCW-60 version alpha (right). The white balance has been made on the white fabric. The pictures represent accurately the sensation given by the special illumination.

Figure 8 “Yellow-free zone” (2018), metro station “Maashaven”, Rotterdam, NL

Figure 9 “Yellow zone/yellow-free zone” (2019), installation and performance in the Whitehouse Gym project space, Lovenjoel, BE. Two zones are delimited by two matching white lights. In the “yellow zone” the white light has a conventional colour rendering (the big balloon appears yellow), in the YFZ, the balloon is almost red.

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