Dynamic colours in dynamic light

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ABSTRACT
The study examines the correlation between colour and light, and specifically the phenomenon of metamerism. The aim of this work is to make a wallpaper with a pattern that varies in different lights. The study contains a theoretical overview, a description of the physical factors that govern the relationships between colour and light and what humans can perceive with their vision. The theoretical part also provides a review of the technical equipment that has been used during the project for colour mixing and light tests. The report finally set out the work process that led to a combination of instable and metameric colour blends which will be used for a wall paper printing.

Background
The project has its origins in a separate study made during the course Color and Lighting orientation held at the Studio of Perception / the University College of Arts, Crafts and Design, Stockholm in August 2009 under the leadership of Ulf Klarén, Anders Winell and Gösta Wessell. The work resulted in a number of colour blends that were clearly unstable and showed a shifting nature in visual tests of a light cabinet. The discovery of how the composition of pigments affects the colours in different lighting gave suggestions for further studies. Unstable or metameric colour blends is something that the paint manufacturers usually consider to be a defect, and strive to avoid. The idea for the further study use the phenomenon as a quality.

Objectives
A major motive for the study is to result in a physical product that can demonstrate the idea of using metameric colour blends as a quality. The ultimate goal is to produce a wallpaper with harmonizing unstable and metameric colour blends that make the pattern change in different kinds of light. By printing a number of unstable colour mixtures on a wallpaper, the pattern could be made to vary and yet harmonize in different sorts of light. One of the purposes of this wallpaper could be environments where people are staying for a long time and where there is a lack of visual stimulation, such as offices or nursing and education environments.
To achieve this, the correlation between colour and light will be examined, and especially the pigments, light sources and technological tools used in the project. The focus of this study is to achieve a better understanding of metamerism and the methods of creating unstable colour mixtures, as well as a greater understanding of which combinations of colours and lighting give most evident effects.

The project is implemented in collaboration with Alcro-Beckers, Philips Lighting and Hand Printed Wallpaper AB, with financial support from Bertil & Britt Svensson’s Foundation for Lighting. It is under the supervision of Karin Fridell Anter, Associate Professor at the Royal Institute of Technology and Researcher at the Studio of Perception / the University College of Arts, Crafts and Design. Furthermore, she is also the Science Officer of SYN-TES, which is a Nordic research and collaborative project in the field of colour and light.

**Spectral power distribution**

Light is often described as radiation from the “visible radiation range” but the human eye can not see the light radiation. The radiation that makes light appear are electromagnetic waves in the wavelength range of 380-760 nm. We can not see the radiation itself but if the waves within the range are refracted in a prism, we can perceive spectral colours when each colour corresponds to a particular frequency in the spectrum. The light that we can see is either directly from a light source or indirectly as reflected light from a surface. The light’s spectral distribution have a significant impact on how the reflected radiation is experienced and it affects how we perceive specific colours. And the spectral distribution is different for different kinds of light sources.

The three main principles for the production of artificial lights are incandescent light in bulbs and halogen lamps, discharge lamps that create light in fluorescent lamps and a number of other light sources which are most common in outdoor fixtures, and electroluminescence which is the technology used for LED:s. Incandescent light gives a continuous spectrum of light similar to daylight, but with a predominance of long wave light radiation. The daylight is perceived as white because it contains all the wavelengths but it is also possible to create white light that contains fewer wavelengths according to the principle of additive colour mixing, RGB, which is a technique often used for lighting for effect. In order to create white light in fluorescent lamps, the coating converts the radiation with a dominance in certain frequency ranges resulting in a discontinuous spectral distribution - but also in a white light. (Fig. 1)
White LED:s are created in a similar manner as the fluorescent lamps. Diodes have a monochrome light produced by a semiconductor which emits light when an electric current passes through it. There are still no semiconductors on the market that can emit white light. The white LED light can be produced either by mixing the light with red, green and blue diodes, according to the RGB principle, or by converting light from a blue diode. This is made by a coating in the same way as with fluorescent lamps, which adds medium wave and long wave radiation to the emitted light.

**Light colour and colour temperature**

The term light colour refers to the colour of the white light as we see it; if it is perceived as warm or cold. The physical term is colour temperature (Fig. 13) and is measured in Kelvin, which is a standard unit of temperature measurement in physics. The bulb, as well as the halogen lamp, is a so-called temperature emitter and has a colour temperature of 2700 K. Halogen lamps can have a higher colour temperature up to 4000 K. For both LED and fluorescent lamps, the colour temperature is designed and determined by the composition of the fluorescent powder and can contain colour temperatures from 2300 K to 6500 K, or even lower and higher.

**Dichromatism and metamerism**

The colours of painted surfaces, fabrics and everything else around us are constantly shifting when they reflect the ambient light, but we do not notice it. We would normally respond only if the colours do not change in character when the light changes, as if a painted table surface would continue to be as pure white even if it was illuminated by the yellow-reddish light from a sunset. We do not react to change unless the colour completely alters in character or if there is a reference, i.e. if the shade of two surfaces is similar in one kind of light, but clearly differs in another one.

An extreme example of a material that completely changes colour is pumpkin seed oil, which does this even without a change of the lighting conditions. Inside the bottle, the oil looks reddish-brown but when it is poured out on a plate, it adopts a green colour tone. A much more common phenomenon is metamerism. All colours are more or less affected by the character of light and vary depending on both the amount of light and sort of light source, but the change is often observed only when there is something to compare it with. An everyday example is a textile material, such as a pair of brown socks that can look alike in fluorescent light, but turns out to have different shades of brown in daylight.
The concept of metamerism thus requires the existence of a standard sample or a comparison, which are then called metameric pairs.

**Colours and reflectance curves**
A blue surface reflects a large part of the light spectrum and the reflected wavelengths are determined by the composition of the pigments. This means that what we perceive to be a blue colour for the most part reflects short wavelength radiation, but also a small part of the middle-wave and long-wave radiation. The illustration (Fig. 2) shows reflectance curves of different colours, but in fact the curves can look different from what we perceive to be a similar colour. What we see as a green colour, for example, contains mostly pigments that reflect the medium wave radiation, but it can also be dominated by a combination of pigments that reflect both medium wave and short wavelength radiation, i.e. the wave lengths can produce blue and yellow spectral colours. That is because we do not perceive a colour by the individual wavelengths it reflects, but by the combined effect of those. We can also see colours that are not found among the spectral colours, of which purple is an example.

The spectral distribution of the light and the reflectance properties of a surface affects how we see a colour. A continuous full-spectrum light as the daylight and a discontinuous light with a limited spectrum have different capabilities of being reflected in the pigments. This also explains why metameric effects may occur. Two surfaces that look the same in one kind of light but differs in another, have different combinations of pigments that react differently depending on the qualities of the light.

**Pigments and colorants**
Colour pigments are divided into two categories, inorganic and organic. The inorganic pigments generally have good coverage and are characterized by giving soft colours. Examples of inorganic pigments are earth pigments such as Umber, Terra and Siena or oxide pigments like Titanium oxide, Iron oxide and Chromium dioxide. The organic pigments often have poor coverage and gives bright colours. They may consist of Azo-dyes or Phthalocyanine which are organic compounds, i.e. carbon compounds. Colour pigments are prepared into colorants which provide for the basis for the colour palette. The colorants are then mixed in various ready-made bases, consisting of the types of binders, solvents and colourless pigments which are suitable for a particular product, for example semi-matt wall paint for interior use. The bases can be opaque white (A-base), semi-opaque (B-base) or colourless (C-base). The transparent C-base is often used for bright colour blends, as the white pigment i opaque bases reduces the colour saturation.

Pigments and colorants can also be unstable and shift more or less noticeably in different kinds of light, but the colour-producing companies must strive to use as stable pigments and paints as possible. To determine whether a colorant or a colour mixture is stable or not, people use the NCS system as a reference. It is also possible to obtain information about metameric effects through computer programs used for colour mixing. But in the end, it is the visual evaluation that provides for the most secure information.

A colour can become instable for several reasons. Some of the pigments or pigment blends that are used in Alcro-
Beckers’ colorants are in themselves unstable. This applies to many of the bright colours and in particular the colorants that are a blend of elementary colours such as Yellow-green (YG) or Violet (V). Generally, instability or metamerism is common in the green-yellow field of the colour circle, but it can also occur if you mix complementary colours. There are also pigments that are stable in themselves and that may stabilize a colour mixture, for example Black (SV) and Yellow-oxide (YO). When a colour blend is identified as unstable or metameristic, the recipes are recorded on a list to avoid being used in production.

Philips’ showroom

The light testing in this project has been implemented partially in the light cabinet. It contains of 16 light sources, of which some are compact fluorescent lamps with different colour temperature, metal halide lamps with different colour temperature, two incandescent lights, two LED fixtures and a high pressure sodium lamp. In the shielded room, mainly one kind of fixture has been used for the tests: a LED luminaire that can continuously vary from warm to cold light colour: the Philips iW Blast 50 PowerCore W with adjustable colour temperature between 2700 K and 6500 K.

Project process

Alcro-Becker have a list of metameristic colours, recorded to avoid them going into production. Two colour combinations from this list was the starting point for the first colour blends (Fig. 3). Soon it became apparent that there were too many parameters to keep track of, as the colours had to be adjusted, both to become more unstable as well as to harmonize with each other in different lights. Therefore, the use of a new combination of colours was picked out from Alcro-Becker’s Interior Collection. The colour samples were
scanned and the computer program used for colour mixing gave suggestions for new recipes that had a metamerism effect. But when the new colour samples were evaluated with standard samples from NCS and the Alcro-Becker’s Interior Collection in light tests, the metamerism effect was not very pronounced. Several new colour blends were made in attempt to create both more instable and more stable colour blends. During the process, a new function was discovered in the computer program. It showed both reflectance curves and the calculated deviation of the different colour blends. With the help of the function, new recipes were produced and this time several colour blends showed a clear metamerism effect compared with the NCS standard samples. In order to analyse how the colours would affect each other in different lights, some samples were also mounted in combinations on test strips (Fig. 4).

Result
The fact that metamerism often occurs in the yellow-green area is an established knowledge, and it was also confirmed by the list of metameric colour blends from Alcro-Becker’s. Almost all of them were found in the upper part of the colour circle. But this does not necessarily prove that the colour mixtures from the bottom of the colour wheel would be more stable in general. In this project, a number of colour blends of blue or reddish colours shifted clearly in different lighting. But despite many attempts to blend the colours with different pigment combinations, it was very difficult to get the colour blends to shift in similar ways in different light tests.

One goal for the project was to find methods for the production of metameric colour mixtures. One possible approach showed to be the use of the features that were discovered in the computer program used for colour mixing at Alcro-Beckers. They provide information on estimated reflectance curves and deviation of different light sources for the new formula compared with the original sample. With the help of these functions, it is possible to make an initial assessment of the metamerism effect before the paint is produced. But the final assessment has to be done with a visual evaluation in light tests. Another tool that can be used in further work is the Philips CRV system that provides information on the colour tone properties for many of Philips’ light sources. In combination with the reflectance curves from the computer program, the graphs can be used to get an idea of how the colour blends would react to specific light sources.

A first assumption when the project began was the colour temperature of the light sources to be the decisive factor for creating dynamic and metamerism colour mixtures. The study has shown that this is only partly true: the metamerism effects occur primarily in the light from light sources that show differences in spectral distribution and colour rendering. In this study, the most obvious metamerism effects occurred in the light that has a discontinuous colour spectrum. In tests in the Philips’ light cabinet, the biggest impact was detected in a fluorescent light with CRI 80 and a relatively low colour temperature, 3500 K. However, most of the color blends shifted clearly in character depending on light colour regardless of source, which was most pronounced in the blue and light yellow colour samples (Cicoria and Cream). The conclusion is therefore that it would be possible to produce colour blends for wallpapers or painted surfaces that are both metamerism and dynamic (Fig.5).