SYN-TES: Human colour and light synthesis.
Towards a coherent field of knowledge.

Contributions to conferences 2012

International Commission of Illumination (CIE);
CIE 2012 “Lighting Quality and Energy Efficiency”
19 – 21 September 2012, Hangzhou, China:

Oral presentation: Karin Fridell Anter
A TRANS-DISCIPLINARY APPROACH TO THE SPATIAL INTERACTION OF LIGHT AND COLOUR
Karin Fridell Anter, Cecilia Häggström, Ulf Klarén, Barbara Matusiak
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Karin Fridell Anter, Harald Arnkil, Leif Berggren, Monica Billger, Pär Duwe, Johanna Enger, Anders Gustafsson, Cecilia Häggström, Yvonne Karlsson, Ulf Klarén, Thorbjörn Laike, Johan Lång, Barbara Matusiak, Anders Nilsson, Svante Pettersson, Helle Wijk
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A TRANS-DISCIPLINARY APPROACH TO THE SPATIAL INTERACTION OF LIGHT AND COLOUR

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Abstract

There has so far been very little research on the spatial interaction between light and colour. The Nordic trans-disciplinary project *SYN-TES: Human and light synthesis* is a recent attempt to develop colour and light into a coherent field of knowledge. This paper presents some of its results: A summary of a research overview; discussions, based on literature and own observations, on the relationship between human experience and physical measuring and on the spatial interaction of colour-light-shape; and an empirical study of how colours are perceived behind windows with energy saving filters. We conclude that adaptation should not be regarded as a merely physiological process but that it also includes important cognitive aspects. We also conclude that descriptions and analyses of the spatial interaction between colour and light must be based on visual assessments. The methodology for this needs further development.

Keywords: Light, colour, spatial interaction, trans-disciplinary, adaptation, glazing

1 Introduction

This paper deals with the complex spatial interaction between light and colour. Traditionally this field has been regarded as difficult or even impossible to treat scientifically. Expert knowledge has instead been based on the practical experience and intuition of artists, architects and designers, in a way that can lead to valuable concrete results but does not add to systematic knowledge.

In spite of the fact that colour and light are mentally indivisible in our experience of the world around, colour as such has mostly been researched on as a separate (usually two-dimensional) reality, whereas light has been reduced to its technically measurable characteristics. Thus knowledge of colour and knowledge of light have been two separate fields, with different theoretical starting points, terminologies and research methods. Those who know much about light and those who know much about colour have had very little contact, and their communication has been full of misunderstandings, which has inhibited a creative joint development of knowledge on light, colour and their spatial interaction.

The trans-disciplinary Nordic research project *SYN-TES: Human colour and light synthesis. Towards a coherent field of knowledge* was carried out during 2010-2011. It involved researchers and practitioners specialised on colour and light, from different academic disciplines at six universities and from leading companies working with light sources, paint, colour standards and window glass. Its main aim was to contribute to the development of a coherent field of knowledge including both light and colour, to be studied from a number of different disciplinary and practical perspectives.

In this paper we present some of the results from SYN-TES: A summary of a research overview on the spatial interaction of colour and light, fully published in Swedish (Fridell Anter 2012), a discussion on different scientific perspectives based on an epistemological subproject published in Arnkil et al. (2012), an observation based theoretical explanation of the complex colour–light–shape interaction and an empirical study of how colours are perceived behind windows with energy saving filters. All these seemingly disparate studies focus on the spatial interaction between colour and light, and all aim at adding to the formation of a coherent theoretical and methodological basis for such studies.

2 Research overview

This section is a summary of an overview in Swedish on international research on the spatial interaction of colour and light (Fridell Anter 2012). In this paper, the aim is to give representative examples rather than a full overview, and we have only included a small number of the references given in the full version.

In international research on architecture and design, neither light nor colour are any large issues, and even less attention is given to their spatial interaction. We have gone through the full editions from 2006-2011 of fifteen journals of design and architectural theory from different parts of the world, and found that they include only a handful of articles dealing with colour and/or light, and most of them have presented artistic installations rather than research projects.

In journals and conferences that deal more specifically with colour or light there is quite a lot of research that is relevant in the contexts of architecture and design. Light and colour are, however, largely two separate fields of research and most of the research deals with completely other questions than their spatial interaction. Recently there have been international conferences that have explicitly focused on both colour and light (Zennaro 2010; Schindler and Cuber 2011). There are also a number of books, in different languages, with both light and colour in their titles (Valberg 2005; Hårleman 2007; Bachmann 2011). However, those books, articles or conference presentations that deal with both light and colour relatively seldom concentrate on their spatial interaction. There are instead a number of other themes:

- Physiological and psychological aspects of light and colour perception
- Colour rendering characteristics of light sources
- Human psychological and biological reaction to coloured light
- Artistic work using coloured light
- Description and/or analysis of light and colour design in specific architectural contexts

There is also research dealing with light and space in a more integrated way. One set of questions deals with the influence of light on spatial experience. Some such questions have been: How are the experienced shape, size and proportions of a room affected by the form and placement of windows (Matusiak 2004, 2006), by the amount of daylight (Matusiak and Sudbø 2008) or by the direction and spatial distribution of artificial light (Wänström Lindh 2010). Other studies deal with the experience of different lighting solutions by visually impaired people (Matusiak et al. 2009) and with the search for lighting solutions adequate for different activities in such as offices (Kronqvist 2010; Galasiu and Veitch 2008), schools (Govén et al. 2010) and hospitals (Stidsen et al. 2010). There have also been studies on how lighting effects the experience of spatiality in an otherwise dark exterior environment (Johansson et al. 2011; Wänström Lindh 2011)

Only a few studies deal with the interaction between light and colour in built spaces. Billger (1999) has carried out a pioneer work on the effects of different lighting on colour perception and spatial experience, and developed methods and concepts for identification and comparison of colour experiences under different conditions. Fridell Anter (2000) has made similar studies on the interaction between facade colours and daylight of different types. Other researchers have investigated how colour perception and spatial experience can vary in rooms with daylight from different compass directions (Hårleman 2007), in rooms with different types of window glass (Pineault et al. 2008) and in rooms with differently coloured artificial light (Vogels 2008). Two pilot studies within the SYN-TES project have developed methods for investigation of the complex interaction between colour and light in spatial contexts . There are also studies with the objective to reveal the principles behind historical architectural work through an analysis of how colour and light were brought to interact (Tantcheva and Häggström 2011)

The surveys mentioned above have been carried out with the help of subjects who spend time in real rooms or judge real life 3-dimensional models. There is also research that uses strongly controlled laboratory experiments and try to develop mathematical models for how colours are perceived in different spatial contexts. Such *Colour appearance* studies are often related to CIE:s Division 1, which works with colour, light and vision. Some examples of such studies are Xiao et al. (2010); Kutas and Bodrogi (2008) and Gombos and Schanda (2006).

3 Human experience and physical measuring

Within research and practice regarding light and colour there are at least three distinctly different approaches: A strictly physical approach, a perceptual approach starting from human experience and a psychophysical approach that strives to use physical measurements to catch human experience. Different perspectives on the complicated relationships between what we can see and what is physically measurable are discussed in Klarén (2012).

Colour and light are what we *see*; to see colour and light logically distributed in space *is* to see. What we, however, without hindrance and so vividly, *experience* is a coherent surrounding world full of life. Our vision is based on a continuous adaptation to the physical world, where colour and light are perceived from endlessly varying spatial positions and under continuously changing light conditions. But although colour and light are mentally inseparable in our experience of the world around, the mutual and dynamic relation between colour and light experiences has not been given attention.

Light and colour science often implicitly assumes an analogy between measurable facts and perceived phenomena, and there is a tendency to regard deviations from this analogous relation as illusions, perceptual misunderstandings, subjective distortions or methodological mistakes. The perceived phenomena provide, however, our only direct access to the world around. In spite of its starting point in empiricism, the study of the physical reality can seldom be carried out by direct observations. Of necessity, scientific descriptions of the physical world have to be indirect – reached by quantifying and by measuring. Hence the 'true' world of natural science could be described as an abstraction constructed by quantitative values, which are interpreted from concepts belonging to the physically based worldview. In the physical world – beyond the reach of senses – the existence of colour and light can only be demonstrated indirectly by measuring spectral electromagnetic radiation with wavelengths between approximately 380 nm and 760 nm. Physical or psycho-physical measuring does not describe the overall impression of spatial variations of colour and light; it does not describe adaptation of lightness and hue or experiences of colour and lightness contrasts. Whereas the ultimate purpose of human perception and cognition is to achieve and maintain a continuous, constant and coherent world, the measuring instruments are only confined to tell what is true about special points of measurement at special moments. Such measurings, however exact they may be, cannot capture the fullness of human experience.

It is true that experience of colour and light is dependent on electromagnetic radiation. Valberg (2005:266) states, however, that "the reflection properties of surfaces relative to their surround are more important for colour vision than the actual spectral distribution reaching the eyes". Hardin (1993:xxi) concludes that there is no reason "to think that there is a set of external physical properties that is the analog of the fourfold structure of the colors that we experience".

Our vision has access to a dynamic flow of continuously varying retinal information interplaying with complex information from all other senses, about spatial colour and light relations, about spatial movements, about our present position in space. Gibson (1979) describes an ecological approach to perception; there is a tight perceptual attunement between human beings and their environment. The perceptual relationship between the outer world and the human inner world is natural and without hindrance. Noë (2004:155), referring to Gibson, comments that "the perceptual world (the environment) is not a separate place or world; it is the world thought of from our standpoint (or any animal's standpoint) ". It is the special human perceptual niche, in ecological balance with the human environment. Appearances are genuine features of the environment. Hence colour and light, in Gibson's ecological sense, are *natural* but *non-physical*. (Noë 2004:155).The Swedish perceptual colour notation system Natural Colour System, NCS, is *natural* in Gibson's sense.

Merleau-Ponty (2002:355) discusses how we experience the surrounding world in different ways depending on situation. He makes a distinction between two modes of attention: *the reflective attitude* and *living perception*. This distinction is significant to our perception of colour. When perceiving colours our vision does not recognize the absolute intensity or the absolute spectral distribution of radiation that reaches our retina. Instead *distinctions* and *relations* are registered. Our visual system is developed for a continuous spectrum of light and gradual changes between different illuminations, and under these circumstances we perceive colours as more or less constant. Colour perception depends on the total viewing situation, and our adaptation adjusts the perception of the whole scene according to its illumination. Gilchrist et.al (1999) argue that a perceived white functions as an "anchor" for perceived lightness of all other surfaces seen simultaneously. Our studies indicate that perceived white serves as an anchor also for the perception of hue and thus to colour constancy. If one part of the visual field is much lighter than the rest, it tends to be seen as white, and the hue of all other surfaces perceived in relationship to this white anchor. Thus the potential chromatic effect of the light source is partly dismissed. This is, however, not total, on the contrary we always keep a slight perception of hue and never experience absolutely neutral – achromatic – colours. This helps us to understand the character of the light source and to name it in terms of warm or cool (Klarén and Fridell Anter 2011).

Depending on *modes of attention,* a nominally white wall lit by 'warm' sunlight can be seen (with a reflective attitude) as slightly yellowish or (with living perception) as the "proper" or "real" colour of the wall experienced beyond the perceived colour. We have suggested that this colour could be called *constancy colour* (Arnkil et. al 2012:24). According to Noë (2004:131–132) different kinds of visual appearances can be experienced simultaneously. Noë gives an example from shape perception: When a circular plate is held up at an angle, we are able to experience circularity in what we simultaneously perceive as an elliptical shape. In the same way, we can experience, say, a white constancy colour in a surface that we simultaneously perceive as having a hue caused by light. (Figure 1).

Figure 1 – The nominally white snow can be seen as slightly bluish and yellowish as effects of sunlight and shading or as pure white as a whiteness anchor. Beyond the perceived colours we feel the constancy colour, the 'proper' or 'real' colour of snow. (Photo: Ulf Klarén)

All these colour and light interactions are what makes us perceive space. Normally we have no difficulties in making distinctions between what is caused by the light and what by the qualities of surfaces and intuitively the logically distributed colour variations caused by light, reflections and shadings are indispensable spatial qualities. Human experience of colour and light in space is both perceptual and cognitive. What we call adaptation is not limited to basic physiological reactions; it is an interplay between the individual and the world on many levels. These include the basic level of innate reactions, the level of perceptive skills based on direct experience of the world and the level of cultural context.

4 Visual shape, colour and light

Our tendency to dismiss the potential chromatic aspects of light is clearly demonstrated by Häggström (1997). A relief, shaped as connected tilted cubes (Figure 2), was painted with nominally neutral grey nuances in a *constructive* pattern. Constructive painting implies adding surface colours that interfere with the shape-defining pattern of light and shade given by the light situation. Lighter surface colours on shaded parts and darker on lit parts work as *countershading* (Figure 2a), while stronger contrasting surface colour differences work as *disruption* (Figure 2b), which visually breaks up the shape-defining pattern given by the light situation. Constructive painting combines countershading and disruption in a way that result in visual reshaping (Cott 1940; Häggström 2009).

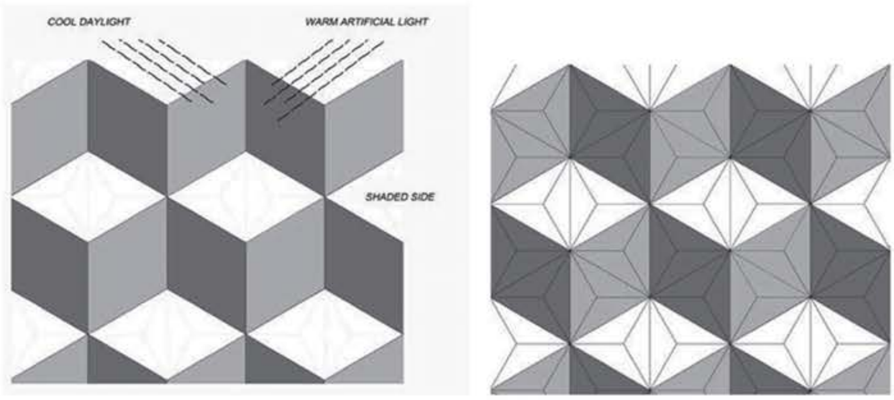

Figure 2 – a) Painted colour differences produce countershading in this light situation. Most light falls on the upper right, darkest plane of the cube, least light on the white shaded plane. b) Outline of added painted constructive pattern that breaks up and reshapes the plane

This cube relief was constructively painted to give, in a specific light and observation situation, the visual impression of pyramids. When it is viewed with a functioning stereoscopic vision of depth, you can clearly see the cubic shapes. At the same time you also perceive that the surface colours have no or minimal differences in hue. They all appear grey, even when lit from different directions with differently coloured light – say warm artificial and cool daylight. However, when you close one eye, or increase the viewing distance enough to eliminate the stereoscopic vision, the perception of cubes is lost. Instead you see the shape of pyramids and simultaneously the surface colours turn from neutral grey to chromatic, in this case golden brown and blue (Figure 3). Slightly different hues given by the warm and cool tints of the light can be perceived also with stereoscopic vision, but when these hues appear *as* surface colours the chromaticness increases distinctly: the colours are clearly not grey anymore. Thus we can see that when colours belonging to the light are freed from their shape defining function, and appear as surface colours, they become more colourful. Our tendency to perceive light as neutral is thus not only a matter of physiological adaption, but is also depending on our seeing of light *as* light – and this is apparently strongly connected to our perception of shape.

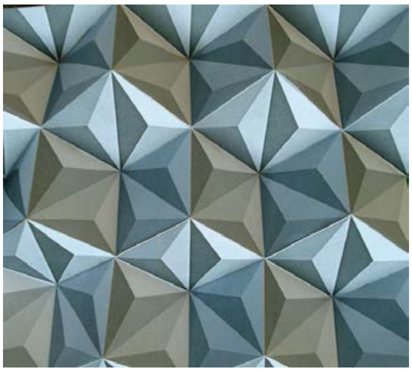

Figure 3 – The appearance of the relief in figure 2 when viewed with eliminated stereoscopic vision of depth

The effect of constructive painting implies perceiving three-dimensional shape incorrectly, and thus actually shape-defining differences between light and shade appear as surface colour differences. The conclusion that incorrect perception of shape also result in increased chromaticness of colours given by light and shade is confirmed by reinterpretation of a classic example: Hurvich's (1981) demonstration with a folded white paper, placed on a table so that is lit from one side by daylight and from the other side by incandescent light. Viewed like that the paper still looks white. However, when viewed through a tube (or anything visually framing of the spatial context) the correct perception of shape is eliminated and the two surfaces of the paper appear distinctly bluish and yellowish.

This way we can also explain the observation by Logvinenko (2009) who used an optical instrument to manipulate our stereoscopic vision: a cast shadow turned clearly blue when the vision of depth was reversed and resulted in a false perception of shape. Billger (1999) made similar observations related to two full-scale rooms. One had all the small colour variations that are normally caused by light, and in the other room these variations were deliberately reduced by painting in counteracting colours. The colour variations over plane surfaces were observed t affect the visibility of shape so that the first room appeared more distinct, while the room where the variations had been painted away appeared diffuse or "flat".

The visual separation of colour, light and shape (Häggström 2009) implies that a shape-defining light normally is perceived as more or less neutral. With shifted visual separation between colour and shape, and certainly technically speaking, the same neutral light may, however, be very colourful. Colour, light and shape are clearly interdependent and the visual distinction between them seems to be pattern-based. The separation is not perfectly stabile, and in interior architecture the distinction can easily be shifted by colour design, resulting in unexpected effects on both colour and light appearance (Häggström and Fridell Anter 2012).

5 Perceived colours behind glazing

We consider daylight, called often natural light, as the most natural source of light, natural because the human visual system developed throughout millions of years in relation to it. Daylight is used as an exemplary reference for electrical light sources especially regarding colour rendering.

Is the daylight delivered through modern glazing different from the daylight outdoors? The spectral distribution of daylight is typically changed by a glazing resulting with slightly change of colour perception of most surface colours. Glazing industry has developed the Colour Rendering Index (R_a) to classify glazing depending on the degree of the change. R_a states if a colour distortion (comparing to daylight outdoors) can be expected and how strong it may be, but it does not give any information about which colours may shift in which direction and how much.

The necessity of a dramatic reduction of energy consumption in buildings nowadays causes the need for much higher energy efficiency. Regarding façades, the easiest way to obtain this is to reduce the size of windows. A conflicting issue is the resident's needs for sufficient daylight level, visual comfort and a nice view. To meet these seemingly conflicting needs, new glazing solutions are being developed, as multilayer glazing with diverse coatings and foils or sealed glazing units filled with a translucent thermal insulation material e.g. silica aerogel.

How much the colours change their visual appearance due to a given type of glazing and in which direction they change, e.g. hue and nuance? The study aiming at answering this question was carried out in the overcast sky simulator at NTNU (Matusiak et al. 2012).

28 NCS colour samples were tested in a scale model, to which different glazing types (or no glass) were fixed. The model had two identical and separate chambers. A hole on the top allowed the observers to look into both chambers at the same time and make a visual matching between samples placed in the first and the second chamber, each illuminated by light transmitted by different glazings (or no glazing). In order to give the colour samples the same illuminance, vertical blinds were used in front of the chamber offering the highest light level. The interior surfaces of the model were covered with a black, matte paper.

All glazings were evaluated visually by observers twice, with the colour samples seen against a white and a black background. Observed colour shifts were slightly larger when the samples were seen against black background than when seen against a white background. This result was expected for two reasons: the adaptation to lower luminance of the black background means higher sensitivity of visual system and the fact that we use white as an anchor for judging all other colours in our visual field. With both backgrounds, the colours shifted in the same direction. As our aim was to detect patterns and tendencies rather than exact measurements of colour shifts, we decided to use only the observations against black background for further analysis.

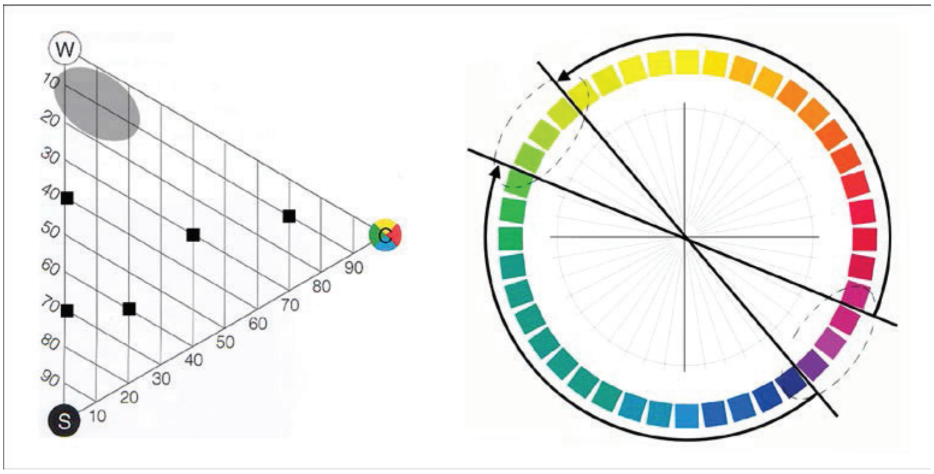

Figure 4 – To the left; approximate area where the nuances proved sensitive to hue shifts caused by glazings (shaded area). The points show tested nuances that did not prove sensitive to such shifts. To the right; principle of hue shifts.

All the tested glazings showed similar patterns for colour shifts. Surfaces with pale colours - with little blackness and low chromaticness - are very liable to shifts both in hue and nuance, whereas strongly chromatic, intense colours and dark colours tend to be much more stable.

The typical pattern for hue shifts is shown in the NCS circle; the pale colours seen behind the tested glazings in comparison with how they look in unfiltered daylight. The arrows shows the directions of the colour shifts; from a colour sample seen in daylight to the same colour sample as seen behind the test glazings. The figure shows only the directions, not the sizes of the colour shifts. The lines through the circle points to the violet and yellow-green "breakpoints" for the colour shifts. Different glazing can give various breakpoints. Within the oval, stippled areas, the colour shifts are therefore extremely difficult to predict.

Typical patterns for nuance shifts varies in different areas. Pale samples with nominally yellowish or greenish hues, tend to get the chromaticness increased when seen behind glazing, while nominal neutral greys tend to achieve a slight yellowish-greenish hue. For samples with nominal hues between red and blue, the opposite was found and the chromaticness was typically reduced. The palest light blue sample assumed a distinct chromaticness in a hue between yellow and green. All these shifts seem logical, given the fact that all glazings had an obvious yellowish-greenish colour and thus functioned as yellow-green filters for daylight.

Since the perception of a surface colour depends (partly) on the spectral distribution of light reflected from the surface, the comparison of spectral distribution of light reflected from a sample illuminated by glazing-filtered light with not filtered light should give a clue about the possible colour changes. Figure 5 shows spectral power distribution measured in the model in the same setting as visual evaluation in daylight laboratory at NTNU for 6 NCS-samples and for two situations: no glass and 3-layers low-energy glazing. The measurements were done in Feb. 2012 by Peter Nussbaum and Aditya Suneel Sole using the Spectroradiometer CS-1000 from Konica Minolta.

The results for 6 NCS-samples and for two situations: no glass and 3-layers low-energy glazing are presented in figure 5. The power of light is strongly reduced by the glazing in the whole spectrum. The difference between the spectral distributions of the grey sample measured with and without glazing shows clearly the physically measurable reason for the change of colour perception investigated by observers. The reduction in both ends of the spectrum is respectively 65% for blue and 70% for red while the reduction in the middle part of the spectrum is lower, i.e. 50%. Similar wave length dependent reductions may be observed for all other colour samples. This confirms the validity of results from visual examination, especially about colour shift from red and blue toward yellow-green.

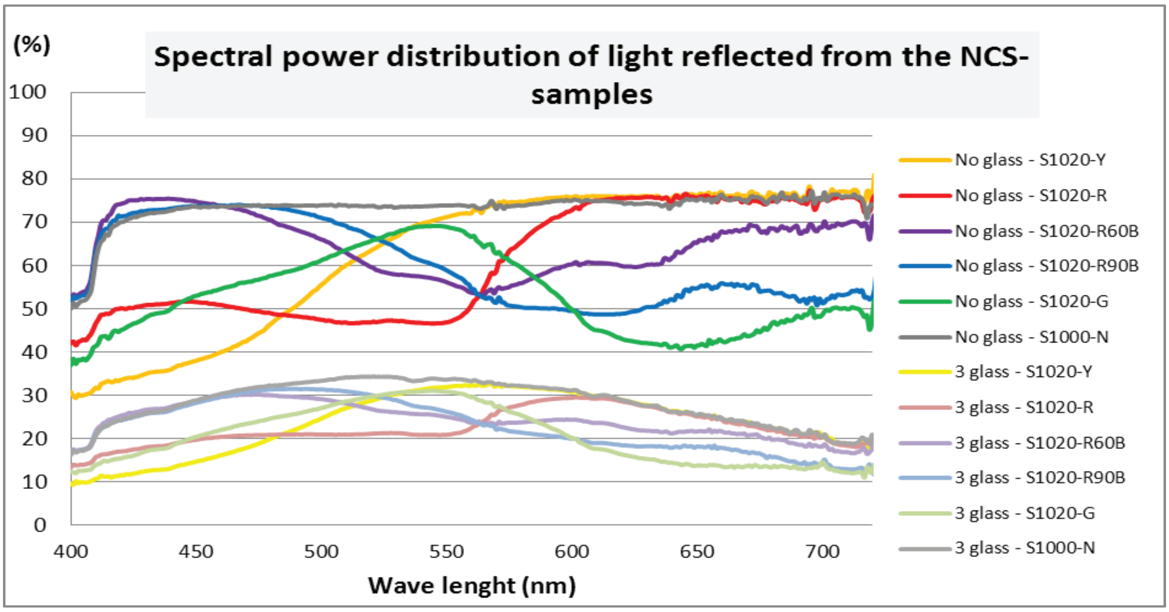

Figure 5 – Spectral power distribution of light reflected from the NCS-samples, indicated in percentage of a perfect white sample

6 Concluding discussion

The theoretical and empirical studies presented above draw our attention to a number of questions regarding the many aspects of visual adaptation and the difficulties to measure and describe human experiences of light and colour in the diverse and complex situations of real life.

First we can conclude that adaptation should not be regarded as a merely physiological process but that it also includes important cognitive aspects. In addition, it is never absolute. Although we adapt to the intensity and spectral power distribution of ambient light, we keep a slight perception of the colour of light. In that way we can understand such as the time of the day and the type of illumination, and describe the light in such terms as warm, cool or gloomy. These small differences between lighting situations are very difficult to measure or describe in other ways than by putting words on our experience. A digital camera is programmed to measure and automatically adjust to the lighting situation, but its “whiteness anchor” is much more rigid than the subtle dynamic multitude of human perception. This means that the small perceived differences between such as different daylight situations are likely to get lost when photographed. A camera using film offers the opposite problem: The only possible adjustment to the situation is the choice of film quality, and without the adaptation processes of human visual sense the pictures are likely to show contrasts and colours that we do not experience in the real scene. The spectral power distribution of radiation reflected from a surface can be measured with a spectroradiometer, but the result alone cannot give us a final answer about perceived colour of the surface, since other parameters that also influence colour perception are not accounted for, i.e. the optical qualities of surrounding surfaces, the quality of lighting and the adaptation state.

The cognitive component of adaptation can obviously not be captured by any instrument, as demonstrated in the relief discussed in section 4. On the contrary, surfaces reflecting identical radiation can be perceived as having very different colours, depending on our (false or correct) understanding of the spatial context. This means that an analysis of the complex spatial interaction between light and colour demands that the totality is taken into account, and thus has to be based on visual observations by observers who are trained to use a reflective mode of attention and a coherent and adequate terminology. When it comes to comparisons between different spatial light situations, adaptation adds several difficulties, as you cannot be adapted to more than one situation at a time. Small colour differences between differently lit scenes tend to be exaggerated if you attempt a direct comparison.

What can, however, be visually compared between light situations, is the contrasts and relationships between colours. In the study presented in section 5 this was shown in rooms lit by daylight filtered through energy saving glazing. The relationships between colours are likely to be decisively affected also when seen under different light sources, notably such that lack the continuous spectrum that our adaptation ability is developed for. This calls for methods to measure and present the colour rendering properties of glazing and light sources in a way that does not start from separate colours but rather from perceived colour contrasts and perceivable colour ranges.

We conclude that descriptions and analyses of the spatial interaction between colour and light must be based on visual assessments. The methodology for such assessments is, however, not very developed, and calls for further research. It must also be held in mind that visual assessments have another kind of accuracy than physically based measurements. Their preciseness can be seen as a mirror of the fact that the world around, with its colours and constantly changing light, is perceived as a totality. Our total experience includes much more than those aspects that can be strictly defined and precisely measured, and even if we can measure more and more of these aspects, their interaction is unique in every situation.

The aim of visual perception is to understand the environment that we live in. From the moment we are born (or even before) our mind creates a mental picture/model of the environment. The visual system (eyes and brain) works constantly and updates it. The physical world, although relatively stable, is perceived from endlessly varying spatial positions and under continuously changing light conditions, and still we can experience its stability. To make this possible, the visual system separates the information about a surface from the information about the light falling on it so we can perceive a surface having stable qualities, e.g. colour. The colour constancy is just necessary to maintain the stable model of the word in our minds. From the evolutionary point of view it is very important, since we need to evaluate the environment as safe-not safe or favourable-not favourable for us.

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In Color We Live: Color and Environment

Interim Meeting of the
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SYN-TES
Interdisciplinary Research on Colour and Light

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ABSTRACT

Colour and light have largely been considered as belonging to two different fields of knowledge, having disparate theoretical, terminological and methodological traditions. This creates a ground for misunderstandings and obstructs a fruitful interdisciplinary and inter-professional collaboration. A survey over international research literature from 2006 -2011 shows that there has been only little research on the spatial interaction between colour and light, but that the interest for this area has recently increased. The interdisciplinary Nordic research project *SYN-TES: Human colour and light synthesis. Towards a coherent field of knowledge* was carried out during 2010-11. Colour and light experts from Nordic universities and companies investigated different aspects of the spatial interaction between colour and light and its importance for human beings. This paper deals with the general learnings from the process. Specific results are presented in other papers at this conference.

1. BACKGROUND

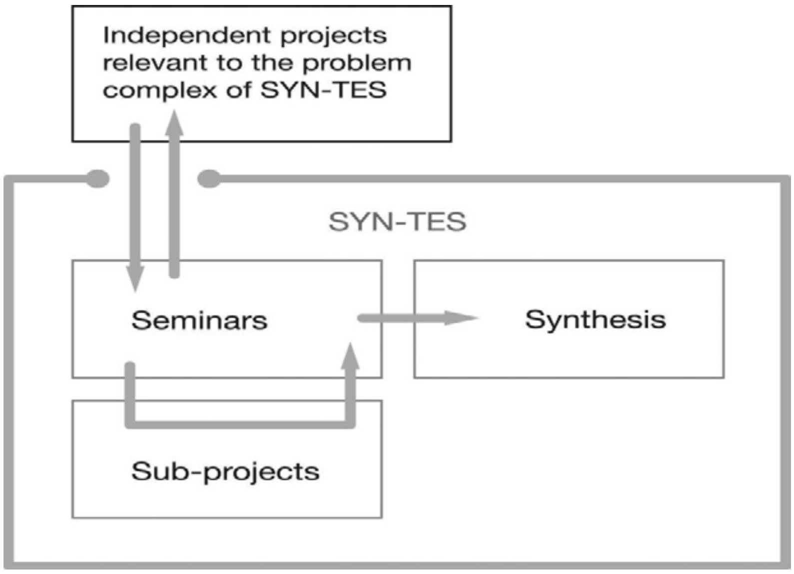
Colour and light are inseparable in our experience of the world and together form our visual experience of space. Until now, colour and light have, however, largely been considered as belonging to two different fields of knowledge, having disparate theoretical, terminological and methodological traditions. This creates a ground for misunderstandings and obstructs a fruitful interdisciplinary and inter-professional collaboration. The interdisciplinary Nordic research project *SYN-TES: Human colour and light synthesis. Towards a coherent field of knowledge* was carried out during 2010-11. Its main aim was to contribute to the elimination of barriers between different thematic, scientific and professional approaches and thus forward the development of a coherent field of knowledge, dealing with both colour and light from a multitude of starting points.

A survey over international research literature from 2006 - 2011 (Fridell Anter 2012a) shows that there has been only little research on the spatial interaction between colour and light, but that the interest for this area has recently increased. Two large conferences in 2010 - 11 (Zennaro 2010, Schindler & Cuber 2011) dealt explicitly with both colour and light, though most contributions still examined them separately. We therefore venture to claim that, seen in a contemporary international perspective, the trans-disciplinary approach that characterizes SYN-TES is unique.

2. TRANSDISCIPLINARY COLLABORATION

Within SYN-TES, colour and light experts from six Nordic universities and four large companies have gathered in totally eight workshops and seminars to investigate different aspects of the spatial interaction between colour and light. The participants come from the academic fields of art, design, architecture, health and care sciences, environmental psychology and visual pedagogy and from companies working with paint, lighting equipment and colour standards. Each of them was already active in research or development work regarding colour and/or light, which meant that everybody could give informed and relevant contributions to the discussions. Some seminars had a broader participation including practitioners from architecture and lighting design and a leading manufacturer of window glass. The main aim of the seminars was to learn from each other and together clarify positions, misunderstandings, agreements and disagreements. The process was allowed to take time and involved a gradually increased confidence, respect and sense of joint effort amongst participants with very different scientific and/or professional backgrounds.

Each seminar was held in the premises of one of the participating academic institutions or companies and included the use of experiment equipment, demonstration of production processes or other specifics that could mutually enhance the knowledge of the participants. Seminars were partly open also to other employees and/or students belonging to the hosting organisation. This gave each one the possibility to learn about other aspects of colour and light than those he/she usually worked with.



SYN-TES also included a number of sub-projects on more specific questions. Each of these actively involved researchers from different disciplines, and most often also practical /technical/design expertise from the participating companies. During the work, the subprojects were discussed in the seminar group and each of them had a double aim: On one hand to identify relevant questions and stimulate discussions within the seminar group. On the other hand to provide new understanding of a specific problem, involving colour, light and their interaction. Reports from subprojects were presented at the AIC conference in Zürich 2011 (Schindler and Cuber 2011, papers by Arnkil et al.; Fridell Anter and Klarén; Klarén and Fridell Anter; Matusiak et al.) and some more are presented in the AIC conference in Taipei 2012 (presenting authors Arnkil, Häggström, Klarén and Matusiak).

3. SYNTHESIS OF DIFFERENT PROFESSIONAL AND SCIENTIFIC APPROACHES

The project highlighted a number of potential misunderstandings and supposed disagreements that had their origin in limited knowledge about different approaches and could be clarified through the discussions and joint practical research work.

One first and very obvious border ran between knowledge about colour and knowledge about light. In a slightly exaggerated way one could claim that those who choose the colours of a room and those who plan the illumination never talk to each other. An interview survey amongst Swedish architects and illumination consultants confirms the great need for educational efforts to bring colour and light specialists to understand each other. (Fridell Anter 2012b). In SYN-TES, one way of doing this was to formulate design tasks to be performed jointly by designers from paint and illumination companies. After full scale testing with observers, both the process and its result were discussed and evaluated by researchers and designers together. This promoted increased mutual understanding not only between experts of colour and light respectively, but also between the designers and technicians with their practice based knowledge and the researchers with their scientific theories and methods.

Another clear difference was that between on one hand natural sciences and technology and on the other hand perception and a knowledge based on experiences gained directly through our visual sense. In the first seminars this difference led to much confusion, and representatives of both sides found it very difficult to understand each other’s viewpoints. Gradually we could sort out that many disagreements were really caused by confused terminology and by the fact that different professions or disciplines define their concepts differently.

4. MAKING THE RESULTS USEFUL

One important aspect of SYN-TES was to forward an enhanced interest for colour and light issues, within relevant professions as well as the general public. For this purpose, results are being presented in different forms, aiming at different readers:

- A series of Swedish language reports, addressing and designed for a broad readership (see www.konstfack.se/SYN-TES)
- A richly illustrated book meant for professionals and non-professionals interested in colour and light issues, in Swedish and hopefully other languages (forthcoming)
- A scientific book in English, specifically dealing with concepts and conceptual confusions (Arnkil ed. 2012)
- International conference reports and scientific articles, aimed at the international research community.

Educational efforts are essential when building a new field of knowledge. Several of the involved academic institutions have had a constant and fruitful interaction between SYN-TES research and undergraduate education of designers and architects. Research issues and results have been presented in lectures by active researchers and practitioners, and students have been involved as observers and in the development of pedagogic tools.

On the post-graduate level, a multidisciplinary PhD course on Nordic Light and Colour was held in Trondheim in April 2012, with participants from several disciplines in four Nordic countries. Within the companies that participated in SYN-TES, the project has resulted in a new approach to in-service training and courses for retail partners.

After completion in 2012 the project lives on as *SYN-TES Nordic Interdisciplinary network on Colour and Light*, open also for others than those who participated in the project.

oral paper

5. CONCLUSIONS

SYN-TES has contributed to the formation of a new and coherent field of knowledge with the human experience of colour and light as its point of departure. The project has produced new knowledge that is fruitful for those working with colour and/or light in their daily practice, by:

- development and explanation of concepts, supporting inter-professional communication
- contributing to understanding of the spatial interaction of colour and light, supporting design and architectural work
- formulating and testing pedagogical and analytical methods of colour and light in space, supporting further educational efforts
- developing and testing scientific methods supporting the research of colour and light in spatial interaction

As part of the process, the group has found good ways of collaborating across disciplines and professions with mutual respect for each other´s competences.

The most important outcome of the project is the experience of creating trans-disciplinary understanding through active collaboration. We hope that the experiences from SYN-TES will stimulate others to convey similar work, gradually approaching the goal of transforming the fields of colour and light into one coherent field of knowledge.

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Always Something Else
- Levels of experiencing colour and light

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ABSTRACT

This paper springs from a project about concept formation in the field of colour and light, and presents a graphic model describing possible constituent relations between colour and light experiences. A deeper understanding of colour and light experiences calls for a coherent and well-defined structure that can be used to describe connections and distinctions between experiences of different kinds. This also can contribute to understanding of how colour and light concepts are related to each other. We experience the world holistically. Our experiences of colour, light and space have many aspects. Their relations to different levels of experience always have to be considered.

1. BACKGROUND

Meaningful experiences of the world are parts of a coherent whole. We *see* colour and light, but what we so vividly, *experience* is a coherent spatial world full of life and meanings. There is a tight perceptual attunement between us and our environment. The experienced world is in ecological balance with the world around. Hardin (1993:xii) concludes that there is no "reason to think that there is a set of external physical properties that is the analog of the fourfold structure of the colors that we experience"

When perceiving colours our vision does not recognize the absolute intensity or the absolute spectral distribution of radiation that reaches our retina. Valberg (2005:286) states that, instead, *distinctions* and *relations* are registered. In this sense you could say that colour and light experiences are natural but non-physical.

Our visual system is developed for a continuous spectrum of light and gradual changes between different illuminations, and under these circumstances we perceive colours as more or less constant. Our visual sense adapts to current light conditions: What we perceive as white in a given illumination functions as a perceptual "anchor" for perception of lightness (Gilchrist et al. 1999) and hue (Klarén and Fridell Anter 2011).

Even if we experience that an object has almost the same colour in different lights, we can at the same time perceive a slight tone of colour that reveals the character of the light. For nominally achromatic surfaces this effect is more obvious than for nominally chromatic surfaces. We may experience that a surface is white, but we feel at the same time that it is illuminated with a light of a special colour and intensity.

Merleau-Ponty (2002:355) discusses how we experience the surrounding world in different ways depending on situation. He makes a distinction between two *modes of attention*: *the reflective attitude* and *living perception*. This distinction is significant to our perception of colour and light. In living perception colours are manifested to us in the totality of spatial relations. Depending on modes of attention, a nominally white wall lit by 'warm' sunlight can be seen (with a reflective attitude) as slightly yellowish or (with living perception) as the "proper" or "real" colour of the wall experienced beyond the perceived colour. We suggest that this spontaneous colour experience is called *constancy colour* (Klarén 2012:24).

All these colour and light interactions are what makes us perceive space visually. Normally we have no difficulties in making distinctions between what is caused by the light and what by the qualities of surfaces. The logically distributed colour variations caused by light, reflections and shadings are to our intuition natural and indispensable spatial qualities.

In addition to the basic perceptual processes and the direct understanding of the world around, human comprehensive experience of colour and light is also dependent of culture. Imaginations, conceptions and ideas *about* the world provide a context to our sense experiences. Noë (2004:1–3) remarks that adaptation is not limited to basic physiological reactions. It is both perceptual and cognitive and derives its origin from multiple sources, external as well as internal. Human experience of colour and light in space is made up from interplay of the individual and the world on many levels.

2. LEVELS OF EXPERIENCE

The human experience of colour and light is multidimensional and dynamic. Its totality cannot be easily described**.** Instead a deeper understanding of colour and light experiences calls for a coherent and well-defined structure that can be used to describe connections and distinctions between different levels of experience. This can also contribute to understanding of how colour and light concepts are related to each other.

Figure 1 shows levels of experience **-** from experiences based on *categorical* – basic – *perception* through *direct experience* of the world around to the *indirect experience* imbedded in cultural expressions.

2.1 Categorical perception

The *categorical perception* gives basic spatial and temporal structure to experience of the surrounding reality. It embraces the basic perception of colour, light and space; colour distinctions and colour similarities, perception of contours and contrasts, balance, verticality and horizontality, movement, etc. The ultimate purpose of categorical perception is to build a comprehensive mental image of the human world: "A reality without well-defined borders is divided up into distinct units by our perceptual mechanism" (Peter Gärdenfors 2000:20. My transl.) . By natural selection man has been endowed certain perceptive and cognitive tools for survival and this is basically common for us all. Categorical perception is in some respects determined genetically, but for the most part acquired in early life.

2.2 Direct experience

By direct experiences we gradually learn through living how to recognize and understand colour and light in the world around. Making use of natural perceptual abilities and interplaying with the physical world humans (and other living creatures) develop perceptual skills; we can intuitively catch the spatial significance of colour and light and the emotional content of spatial situations. Direct experience is dynamic, comprehensive and spontaneous; perceptions, feelings and emotions form a coherent whole.

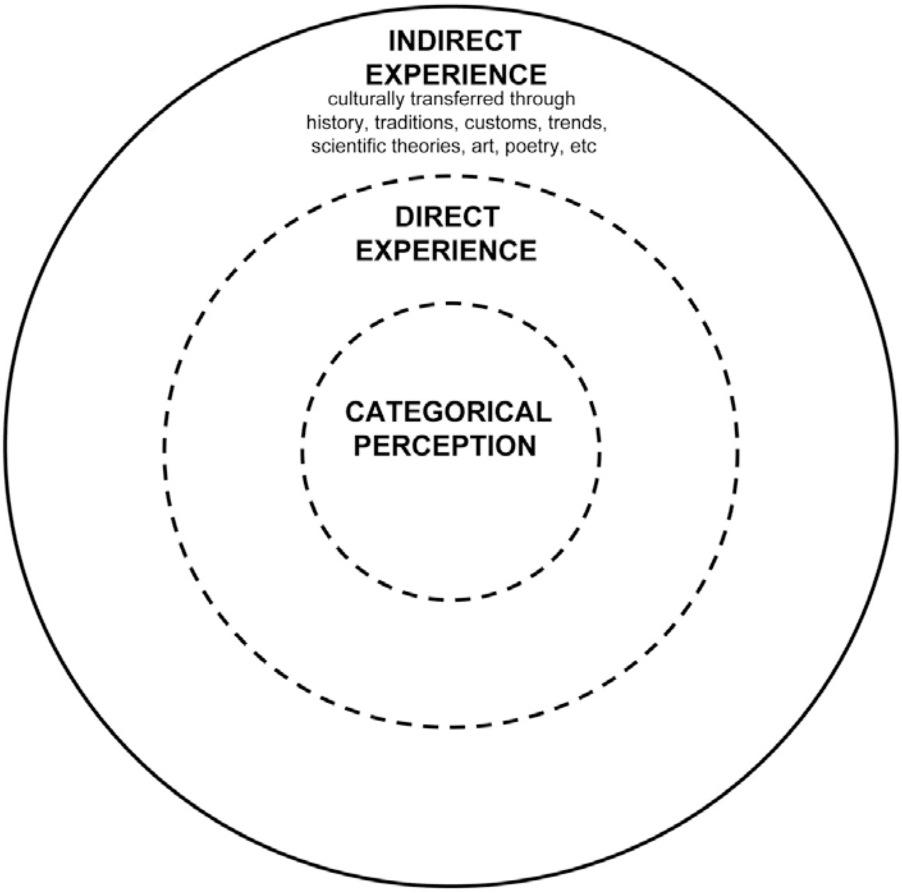

Figure 1. Experience levels (Model by Ulf Klarén)

2.3 Indirect experience

The outer circle embraces concepts and models that help to understand or give perspective to the experienced phenomena in the two inner circles. Indirect experience imbedded in cultural expressions – history, traditions, customs, trends, scientific theories, art, poetry, etc. – form a cultural context that all experiences of necessity are related to. History, scientific theories and theoretical models provide a basis of explanation and analyses, traditions and customs serve as guiding rules, art and design, literature and poetry summarize common experiences; art and design with expressive symbols and appearance of space, literature and poetry with symbols of language.

The cultural and social contents can change and be reinterpreted, but can never totally be taken in or controlled by the individual. It is implicitly present in all perceptions. Abstract figures or words can be associated with symbolic meanings; a colour combination, a special light or a space – as well as many other visual phenomena – may be associated to concepts or feelings. Thus indirect experiences can provide meanings and feelings to phenomena based on direct experiences and categorical perception. Cultural colour and light symbols are, however, basically social understandings. They are arbitrary and can be changed or replaced. Cultural symbols may not be mistaken for the intuitive and emotional content of direct experience.

Indirect experience can relate in different ways to phenomena described in the two inner circles. Concepts used for specifying spatial light situations or perceptual light qualities and concepts used in perceptual colour theory aim to describe a *direct* experience. Likewise a painting describing a special light and colour experience can serve as a concrete artistic 'model' for how we can attend to light and colour in the real world. On the other hand, concepts that describe the outer world in abstract terms based on physical analyses with quantitative *measurements* and *instrumental methods* have an *indirect* relation to experienced phenomena.

The three experience levels are mutually dependant and implicitly present in all perceptions. A perceived distinction between a red colour and other colours is a basic – categorical – perception. The experience of the colour of a wall – whether in light or shadow – is a direct experience of the world around. The knowledge that red has a special position in a colour system, or that red surfaces absorb electromagnetic radiation in a special way, or that red houses may be of high social importance, is based on indirect experience.

3. CONCLUSION

Colour and light are, indeed, "always something else", but our experience is not without structure or laws and there are certainly many concepts describing human experience. One could even say that there are too many – and disparate – concepts to be useful in communication. What is emphasized here, however, is the lack of a coherent and well-defined structure of content. The experience of colour and light has many aspects, and their relations to different levels of experience must always be considered. If colour phenomena are abstracted from their natural connections to light, spatial order and cultural context the causal relations behind them become inconceivable and mystified. Without a comprehensive structure of content it is not possible to see how different kinds experiences – and concepts – are related to each other, or in what respect they refer to different aspects of reality.

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Interior colour design effects on preferred level of light

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ABSTRACT

This study focused on the relationship between interior colour design and preferred level of light. We tested the hypothesis that preferred light level would significantly increase when applying countershading colour design and decrease when applying co-shading colour design. The aim was to identify measurable effects on energy consumption. A test-room, equipped with two alternative lighting scenarios, was painted three times: uniformly warm grey, countershaded and co-shaded. The same 29 observers, male and female of varying ages, made totally 8 adjustments with a dimmer in each colour design – in two different practical situations, from both fully lit up and complete darkness, in each lighting scenario. The total energy consumption for each adjustment was registered by a wattmeter. Each person's results were compared to his/her own and data analysed statistically. The results shows that applied counter- and co-shading principles, working on convex objects where essential shape defining differences appear between planes, cannot be directly applied in the concave room. Thus we failed to achieve efficient co-shading. Unintended effects suggest that applied principles worked rather like *disruption* and that essential shape defining differences in a room appear within each plane. The countershaded room, however, significantly increased the energy consumption – up to 25%.

1. BACKGROUND AND PROBLEM

Colour and light are functionally inseparable in our experience. Understanding their interaction is essential for creating good environments for human life, yet a lot of research is still to be done. In this study we focus on the relationship between interior colour design and preferred level of light, with the aim to better understand colour design effects on interior shape defining patterns given by lighting, and the more precise goal to identify measurable effects on energy-consumption. The project is reported in detail in a Swedish publication (Häggström & Fridell Anter 2012).

Previous research suggests that the spatial organisation of coloured surfaces in a room can affect the perceived level of light (Fridell Anter 2011). We assumed that the preferred level of light depends on the degree of visibility of shape, so that a colour design that enhances visibility of shape should require lower level of illumination than a "neutral" colour design, and that a colour design that decreases visibility requires a higher level of illumination. This function is so fundamental that it ought to measurably affect the preferred level of light. Applying concepts from the *Colour-Shape Interaction Analysis* (Häggström 2009) we formulated the hypothesis that the preferred level of light would increase significantly when applying *countershading* colour design and decrease significantly when applying *co-shading* colour design, compared to preferred level of light with a uniform colour design.

2. METHOD

This pilot study used a test room equipped with two sets of luminaries, creating typically different lighting scenarios: one undirected with mixed light sources and one clearly directed with LED-spotlights. Walls and furniture were painted three times to give us first a uniformly warm grey room, then a countershaded and finally a co-shaded version with the same warm grey main impression. Counter- and co-shading were done by adding darker and lighter nuances in approximately the same proportions but with reversed spatial distribution, that is: countershading with lighter nuances on more shadowed planes and darker on more lit planes; co-shading with darker nuances on more shadowed planes and lighter on more lit planes. Interior decoration details were added to create a more normal semi-private atmosphere.

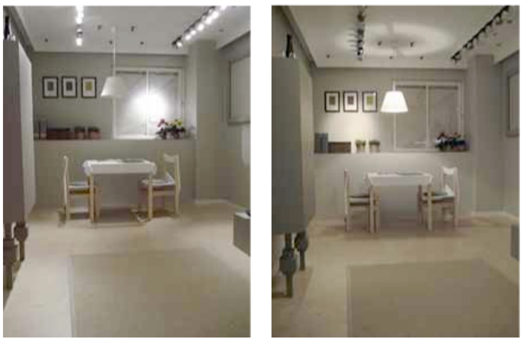

Fig. 1. The two lighting scenarios in the uniformly warm grey test-room: On the left side the clearly directed scenario and on the right side the undirected scenario.

The test included 29 observers, male and female of varying ages, participating through all the study. A form with detailed instructions for the procedure and documentation of values was used, varying the order of judging systematically, starting with dark or light and with directed or undirected scenario.

Each lighting scenario was judged separately. The observer used a dimmer to increase or decrease the total level of light. Between every visit to the test room the observers spent approximately 5 minutes in a daylight room where the level of illumination was reasonably controlled by blinders and complementary artificial light.

Two different practical situations were judged every time the observer visited the room. First the observer was asked to move around in the room and dim up/down to the lowest acceptable level for “staying in this room a whole day without doing anything particular”. Next, the task was to set the most suitable level when sitting by the table, looking at pictures in glossy magazines “as if you were going to make a collage of them”. Both situations were judged twice in each lighting scenario, starting both from completely switched off and from fully turned up light (to avoid the starting-point effects observed by A Logadottir 2011).

The energy consumption for each judged situation was registered with a wattmeter. Watt-values were later recalculated into mean lux-values based on illuminance measurements at 103 points (33 on floor, 70 on wall) at 4 different watt-levels for each scenario. A wide range of other factors, from outside weather and lux-values in the daylight room to self-estimated difficulties with glare and darkness, were also documented.

To overcome the differences between personal preferences of light level, we analysed the results by comparing each person’s results with his/her own in the different experimental situations. The two scenarios were also analysed separately, and all data analysed statistically.

A complementary study was carried out, using 100 observers (55% female, mainly engineering students and in the age 20-29). The subjects were asked to compare two simple counter- and co-shaded empty scale-model rooms, judge differences in lightness and freely comment on other perceived differences. Because of the rough experimental set up resulting in slightly different lighting (both in colour and intensity of light) the two models switched place so that half of the subjects judged the co-shaded model in the lighter position and the other half judged the countershaded model in the lighter position.

Fig. 2. The scale-model rooms, here with the countershaded model, that was judged to be lighter, on the left side where the light was weaker and cooler, and the co-shaded model on the right side, where the light was more intense and warmer.

3. RESULTS

The method of reusing the same observers and comparing each ones result to his/her own proved successful: In spite of huge differences between individuals the subjects were surprisingly consistent with themselves. This was clearly confirmed by the data from five observers that had to remake the third round a week later – with practically identical procedure and design, and remarkably similar result, as shown in figure 3 below.

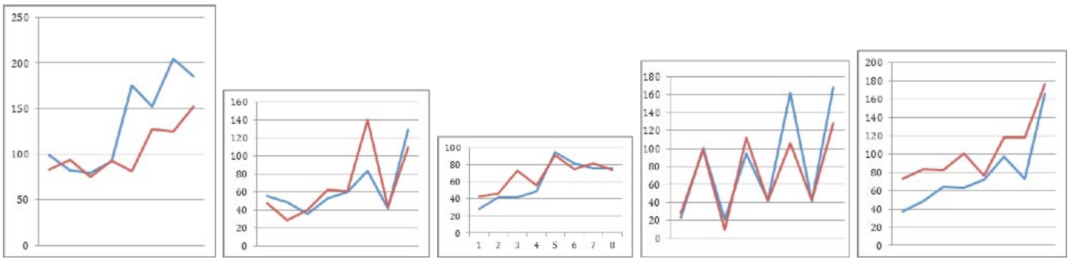

Fig. 3. Lux-mean values (vertical scale) for all adjustments, made by subjects no 12, 15, 16, 24 and 25 which repeated the test in the co-shaded colour design. The graphs show values in undirected (horizontal position 1-4) and directed lighting scenario (horizontal position 5-8): Blue line represent the first time and red line the second time one week later.

The scale-model study confirmed that the room with countershaded planes, that significantly required higher level of light in the full scale study, still was perceived as lighter than the room with co-shaded planes, surprisingly even in the measurably darker position. In both positions the co-shaded was perceived as sharper, or richer in contrasts. In addition a position depending difference in hue was observed – and also photographically documented.

In our result, in spite of resulting in a lighter appearance, the applied countershading significantly increased the preferred level of light. However the assumption that our co-shading should decrease the preferred level of light was contradicted. We suggest that this negative result does not really falsify the second hypothesis, but may instead be explained by unforeseen difficulties to accomplish a functioning co-shading design. It may be like clapping hands in time with music – there are innumerable ways of clapping out of time, but only one way to do it precisely in time.

The applied counter- and co-shading principles work well on convex objects, where essential shape defining differences appear *between* planes. Because of the importance of reflections between walls in a room, these principles cannot be directly applied in the concave room. While just reversing the spatial organisation of darker and lighter coloured surfaces we also achieved unintended effects on the overall colour-impression – and clear differences in hue "taken" from the light was observed in the model study. In addition much bigger differences in nuance could be used (without getting visible) for counter- and co-shading on the planes of convex objects, like furniture, than on the concave room walls. This suggests that the applied principles worked more like *disruption* (Häggström 2009), disturbing shape defining pattern and hence, like camouflage, reducing visibility of shape (Häggström 2009, 2010 & 2011).

Our conclusion is that essential shape defining variations in a room appear also, or rather, *within* each plane. Thus we accomplished no efficient co-shading but with the applied "countershading" we decreased visibility of shape and caused significantly increased energy-consumption – up to 25%. The results show the potential for both saving energy and improve visibility – and with that human wellbeing – by merely avoiding, or adjusting, extra "light consuming" spatial distribution of surface colours.

ACKNOWLEDGEMENTS

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Colour Shift Behind Modern Glazing

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ABSTRACT

The necessity of a dramatic reduction of energy consumption in buildings causes the need for much higher energy efficiency. Regarding façades, the easiest way to obtain this is to reduce the size of windows. A conflicting issue is the resident's needs for sufficient daylight level, visual comfort and a nice view. To meet these seemingly conflicting needs, new glazing materials are being developed, to be used as transparent windows or transluscent façades. As these coatings and materials can be regarded as colour filters, they might cause colour shifts in interiors situated behind such glazings. The main goal of the project was to explore how much the colours change their visual appearance due to a given type of glazing and in which direction they change, e.g. hue and nuance. The study was carried out by observers in the overcast sky simulator at NTNU, and NCS colour samples were tested in a scale model, to which different glazing samples were fixed. All the tested glazings showed the same typical patterns for colour shifts. Although the colour shifts appeared somewhat weaker for the translucent glazings than for the transparent glazings, the tendencies presented are, with small variations, valid for all tested glazings.

1. BACKGROUND

1.1. Project background and objectives

In the global discussions about climate change and energy-efficiency, architecture has moved to centre-stage as buildings offer the biggest energy-saving potential. Until recently, most windows were made of double layer glass, but new demands have lead to a more widespread and accepted use of triple layer glass. For the same reason, new materials are being developed to provide better thermal insulation, especially for use in large glass façades.

The project has been carried out in conjunction with another project dealing with daylight utilization, glare and visual communication when using trasluscent facades (reported separately[1]). The project here presented deals with glazing and its perceived impact on the colours - and the contrasts between colours - in interiors behind different kinds of transpararent and translusent glazings.

The project is a pilot study exploring how different glazings can influence the perceived colours. The two main objectives has been:

- to find relevant questions and develop methodology for testing colour rendering properties of glass, and to form a basis for further research and future analysis of new glazing solutions.
- to evaluate and present colour rendering properties of transparent and translusent glazings available on the market in 2011, thus providing guidance to architects, designers or

[1] The Norwegian Research Council, project 526192- p10_011 Tanslucent facades. A guide for use of translucent facades will be published lated this year. Web address: www.forskningsradet.no.

contractors in the choice of glazing or the design of colour schemes for interiors lit with daylight filtered through such glazings.

1.2. The effect of glazing on perceived room colours

Whereas there are stricly formulated demands on the energy saving aspect of glazing, there are no regulations dealing with their impact on perceived light and colours inside the buildings. The colours that we perceive in a room are essential for our perception of the room atmosphere and for visual clarity and experienced quality of light.[2] A window glass or a translucent façade distorts the wavelength distribution of incoming daylight and thus is likely to affect our perception of colours in the room.

2. METHOD

2.1. Conditions

The experiment was carried out in the Artificial Sky in the Daylight Laboratory at NTNU, simulating a totally overcast sky, based on the CIE Overcast Sky model.[3] [4] Two trained observers made visual matching of colour samples seen behind the tested glazings and in a reference situation. Twentyeight (28) colour samples from The Natural Colour System (NCS) were chosen to give a wide distribution of hues and nuances, and used as reference samples.

The samples were places in a scale model (app. scale 1:10 of a bedroom), with two identical chambers. The model was covered with a non-reflecting black, matte paper, and hole on top allowed the observers to look into both chambers at the same time. All glazings were tested twice, with the colour samples seen against a white and a black background, similar background for both chambers. In order to give the colour samples the same illuminance, vertical blinds were used in front of the chamber offering the highest light transmittance.

2.2. Procedure

A reference colour sample were placed in the reference chamber and compared to the comparison samples placed behind the test glazing in the test chamber. The observers assessed which of a large number of comparison samples - two and two at a time - looked the same as the reference sample seen in the reference chamber. The aim was to investigate situations with both filtered and unfiltered light, or the effect of translucent versus transparent glazings, simultaneously filtering daylight into a room.

3. RESULTS

Observations against white and black background showed that colour shifts were slightly larger when the samples were seen against black bakground as when seen against a white background. This result was expected for two reasons; the importance of adaptation luminance and the fact that we use white as an anchor for judging all other colours in our visual field.[5] With both backgrounds, the colours shifted in the same direction. As our aim was to detect patterns and tendencies rather than exact measurements of colour shifts, we decided to use only the observations against black ground for further analysis.

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[2] Recent studies of the spatial interaction between light and colour have been carried out within the transdisciplinary Nordic research project SYN-TES. See Fridell Anter 2011 and Häggström & Fridell Anter 2012.

[3] For a comprehensive scientific presentation of the artificial sky, see Matusiak & Arnesen 2005.

[4] ISO 15469 CIE S 011/E Spatial distribution of daylight – CIE standard general sky.

[5] White as an anchor for judging colours in our visual field, see Klarén & Fridell Anter 2009.

Observations showed that surfaces with pale colours - with little blackness and low chromaticness - are very liable to shifts both in hue and nuance, whereas stongly chromatic, intense colours and dark colours tend to be much more stable.

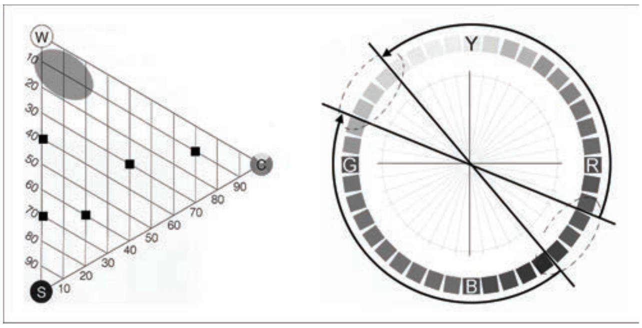

Figure: To the left; approximate area where the nuances proved sensitive to nuance shift caused by glazings (shaded area). The points show tested nuances that did not prove sensitive to such nuance shifts. To the right; principle of hue shifts.

Typical pattern for hue shifts is shown in the NCS circle; the pale colours seen behind the tested glazings in comparison with how they look in unfiltered daylight. The arrows shows the directions of the colour shifts; from a colour sample seen in daylight to the same colour sample as seen behind the test glazings. The figure shows only the directions, not the sizes of the colour shifts. The lines through the circle points to the violet and yellow-green "breakpoints" for the colour shifts. Different glazing can give various breakpoints. Within the oval, stippled areas, the colour shifts are therefore extremely difficult to predict.

Typical patterns for nuance shifts varies in different areas, here shown in the NCS tringle. Pale samples with nominally yellowish or greenish hues, and nominal neutral greys, tend to get the chromaticness increased when seen behind glazing. For samples with nominal hues between red and blue, the opposite was found and the chromaticness was typically reduced. The palest light blue sample assumed a distinct chromaticness in a hue between yellow and green. All these shifts seem logical, given the fact that all glazings had an obvious greenish colour and thus functioned as green filters for daylight.

4. CONCLUSIONS AND DISCUSSIONS

Results shows that the transparent glazing tends to give quite strong colour distortions compared to unfiltered daylight (e.g. open window), and that the tranlucent glazing have a similar pattern, although not as strong. However, these results were reached in a specific laboratory situation and are fully valid only in similar circumstances. The next, and very important, question is to what extent these shifts would occur in real buildings using these glazings.

The most important difference between the test situation and a complex real life situation is that in normal situations you are adapted to the existing light, and colour constancy will make you perceive the colour of a surface more or less the same as in another light situation. This means that you would not perceive these strong colour shifts in a room with the filtered light as the only light source. The existence of (near) white surfaces in the room would enhance the adaptation and colour constancy, as opposed to the totally black surroundings used in the test. On the other hand the colour constancy is considerably weaker in light very different from the natural light and its continuous spectral distribution.[6] Thus, the rule of adaptation and colour constancy cannot easily be predicted in situations other than the tested ones.

Still the tests give ground for conclusions that are essential for the perception of colours in real rooms. The range of colours perceived in the interior will decrease, which will make the totality look more dull and monotonous than when lit though an open window. The balance and contrasts between different colours will be affected, since in some colour areas the contrasts between different coloured surfaces will change drastically, and in different directions, when seen behind the glazing as compared to unfiltered daylight.[7] Since darker and more intense colours are much less affected by the glass, these things can mean that a colour scheme based on hue similarities or on subtle colour differences will change and maybe be ruined if the glazing is not considered throughout the design process.

If different light situations are combined in the same room, this will disrupt the adaptation which might make colours look very different in different parts of the room. For example, if a window - in a row of windows using low-energy glazing - is to be opened and lets in unfiltered daylight, the colours will be perceived dramatically differently. If we are adapted to the greenish light, the unfiltered daylight will be seen as redish blue and also more intense and bright. The daylight will reveal colour contrasts that can hardly be seen when the windows are closed, and certain colours in the room will change character dramatically. If transparent windows are placed in a translucent façade, the light coming in through the windows will be perceived more intense and slightly greener than the dim, diffuse light let in through the translucent glazing. How this will affect our colour perception depends on how we are adapted to the whole, and this will in turn depend on the location and the relative size of the two types of glazings.

In real buildings there are, in addition, a variety of different artificial light sources with different light colours and different colour rendering capacities. Their interacton has not been examined or discussed within this project.

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[6] For thorough understanding of the visual system and colour vision, see Valberg 2005.
[7] The importance of the contrast range is discussed in Fridell Anter 2011 p 38-40.

poster

Colour and light: Concepts and confusions

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ABSTRACT

Colour and light are things that all seeing persons have often reason to refer to, comment and discuss. Such discussions often end up in misunderstandings due to the fact that both *light* and *colour* have several – and often conflicting – meanings. This causes problems for professionals in either colour or light or both, for example when quantifying light, discussing light qualities or specifying an exact colour and its characteristics. This paper summarises a project that aimed at sorting out the confusions and at contributing to a better understanding across different disciplines and professions dealing with colour and light. The project identified numerous conflicting usages and potential causes of misunderstanding in the colour and light terminology. A careful analysis of the most important concepts and their usages was carried out. Three main causes for potential misunderstandings of colour and light terminology were found: 1) confusing the different ways of understanding colour and light through physics, human perception or attempts to combine the two. 2) the confusions caused by different modes of appearance of colour and light and 3) the confusions arising from different of modes of perception.

1. INTRODUCTION

The study was carried out in English, with some references to Swedish and Finnish languages. Despite dealing with terminology, it was not a linguistic project; the focus was on concepts and their use, rather than linguistic differences. We therefore believe that the findings of this study can be readily used and tested in various language environments.

There are two basic approaches to formulating terms that define colour and light. The first is based on our visual experience of the world. This experience spans – as biologically inherited and culturally accumulated knowledge – the whole length of human evolution. The second is based on physics as a scientific way to explore and understand nature. This approach is only a few centuries old and is permeated by a tradition of exact quantification. Psychophysics is a branch of science that aims to bridge the worlds of experience and physics by formulating quantifiable relationships between the two. *Photometry* and *colorimetry* are examples of such endeavours.

Confusions usually arise from words or sentences being understood in diverging ways. One type of confusion arises from mixing concepts belonging to different academic or professional traditions, as in the photometrically defined measure *luminance* and the perceptually defined attribute *brightness*. Another type of confusion is exemplified by *lightness* and *brightness*. Both terms have specific definitions in perceptual science, but at the same time they have their different usages in everyday language.

A third type arises when general experiences or categories have to be further defined for scientific or technological purposes. These can be similar, but not exactly the same, in different conceptual systems. For example, in everyday language we can talk about *vividness* of a colour and be reasonably confident of being understood; but there are many terms in scientific and technical usage, such as *chroma*, *chromaticity* and *chromaticness*, that have similar or slightly different meanings that can still differ from the everyday concept of vividness. Especially problematic are words that are given alternative conceptual definitions in science, while having a more or less stable and established meaning in everyday usage. Take for example *saturation*: even if each of the scientific and technical definitions is clear, it is very confusing that one term can have so many different definitions.

There are also generic words and terms that have very specific meanings within a given scientific discourse, such as the concepts *inherent colour* and *identity colour*. The words *inherent* and *identity* have meanings that can lead to misinterpretations by those not familiar with the scientific discourse.

2. SOME CONCEPTS AND HOW THEY ARE CONFUSED

2.1 Lightness and brightness

The words *lightness* and *brightness* have both wide generic use and specified scientific applications. In everyday usage 'light' and 'bright' are sometimes used synonymously. For instance a room can be described as either "light" or "bright" with reference to either its surface colours or its illumination or both. Modern perceptual science has reserved separate and distinct meanings for these two words: "Lightness is the perceived reflectance of a surface – – Brightness is sometimes defined as *perceived luminance*." (Adelson 2000).

Neither lightness nor brightness can be physically or psychophysically measured. Photometric units and measuring tools are based on methods of measuring electromagnetic radiation as weighed against a theoretical model of the light-sensitivity of the visual system. This gives information about such as the *reflectance* of a surface and the *illuminance* (lux) reaching the surface. The *luminance* referred to by Adelson is measured in candela/square metre and *can* be measured. Luminance has an indirect relationship with reflectance and illuminance, but none of these is the same thing as the experience of *brightness*.

2.2 Inherent, identity and nominal colour

The very word colour is used in a number of conflicting meanings, a matter that has been previously discussed by Paul Green-Armytage (2006). We have identified the following usages of the word: The perceptual aspect of colour includes conventional colour names and terms referring to artistic work, but also perceptually defined terms for scientific use, such as the NCS colour properties. The physical aspect of colour is defined by spectral power distribution. Technological colour concepts are defined from the way colour is produced in a specific process, such as RGB or CMYK, and are not applicable in other contexts. The aim of the psychophysical approach is to describe perceived qualities through the use of physically measurable quantities, such as the units of CIELAB or different colour appearance models. (Fridell Anter 2012).

In The Swedish Institute of Standards edition SIS 1993, 2.6 the terms *inherent colour*, *body colour* and *local colour* have been offered as translations of the Swedish word and concept "egenfärg", which translates more literally into English as (an object's) "own colour". This was based on the work of Anders Hård, whose definition of *inherent colour* was as follows: "… the colour that one imagines as belonging to a surface or a material, irrespective of the prevailing light and viewing conditions". (Hård & Svedmyr 1995, p 215; our translation). Hård´s definition includes a method for operationally determining the inherent colour, which obscures the notion of an imagined 'real' colour: "... it can be operationally determined e.g. through comparison with a standardised colour sample." (Ibid.) Here Hård in effect refers to the standardised viewing conditions under which the NCS samples are perceived to correspond with their codes. Hård implies that the colour perceived under these conditions is equal to the 'real' colour.

Karin Fridell Anter has used *inherent colour* in a meaning different to the above, as a reference point or 'helper concept', to which perceived colour changes of surfaces are compared. Unlike Hård, Fridell Anter makes no claims about the inherent colour representing any 'real' colour. (Fridell Anter 2000, pp 59–64). We suggest, therefore, that to avoid confusion, the term *nominal colour* be used as a more fitting description of the concept behind *inherent colour*.

Monica Billger has introduced in her thesis *Colour in Enclosed Space*, the concept of *identity colour*: "*Identity colour* is defined as the main colour impression of surfaces or parts of a room that are perceived as uniformly coloured." (Billger 1999, p 11). Billger remarks: "The perceived colour is analysed on two levels of reflective attention, one that can be called holistic and one that is more detailed" (Ibid.) By changing our mode of attention we are able to separate the various layers or spatial attributes of perception.[1] This shifting of attention between local and global or between object, light and shadow, is a part of the normal working methods of any visual artist. The difference between the reflective attentions of an artist or visual researcher and those of the 'man in the street' is one of level of consciousness. Neither *nominal colour* nor *identity colour* claims to represent 'the real colour of the object'. The important difference between the two concepts is that *nominal colour* can be measured by comparison to a colour sample, whereas *identity colour* cannot be measured or operationally determined in any way, only perceived through holistic reflective attention.

2.3 Saturation, purity, chroma, and chromaticness

The chromatic strength or vividness of a colour can be judged with perceptual, physical or psychometric criteria. If perceptual criteria are used, they usually apply to 'related' colours; if physical or psychometric criteria are used, they can refer also to 'non-related' colours. A colour's mode of appearance depends largely on its degree of relatedness. In related colours (surfaces, colour chips etc. viewed naturally) the scale of vividness is: neutral white, grey or black – fully vivid colour. In the Munsell colour system, vividness is called *Chroma* and is judged in proportion to a neutral grey of the same value (lightness). In the NCS vividness is called *Chromaticness* and is judged in proportion to the sum of the colour's blackness and whiteness. The NCS includes a concept of *saturation* that is unique and different from all other meanings of the word: colours that lie on a straight line connecting NCS black and any other colour of the same hue display a constant relationship of whiteness and blackness and thus, according to this NCS definition, possess equal saturation. (Arnkil 2012).

In non-related colours (a light source surrounded by darkness, a surface colour viewed through an aperture), the scale can be: darkness (no light or colour) – maximally bright chromatic light (devoid of blackness or whiteness). This is called *Chromaticness* in CIE terms. Alternatively the scale is from neutral achromatic (white) light to fully chromatic light of the same luminance. This is called *Saturation* in the CIE system. (Billmayer & Saltzman 1981).

There are two further terms related to the concept of vividness in the CIE system. *Excitation purity* is a term related to the CIE 1931 xy chromaticity diagram. It relates directly to the psychometric concept of tristimulus values of spectral sensitivity in the human visual system. (Optical Society of America 1973). *Chromaticity* is defined as the hue and saturation of a colour without regard to its luminance. In the CIE chromaticity model a very dark green and a very bright green could have the same chromaticity. The difference between colours of equal chromaticity and equal saturation, then, is that colours of equal saturation may vary in hue whereas those of equal chromaticity may not. (Arnkil 2012)

To add to the confusion, the various three-part formulations of colour of computer programmes, such as HSV, HSL and HSB (based on the concepts of hue, saturation and

[1] See for example: Merleau-Ponty, M. (2002). *The Phenomenology of Perception*. London and New York: Routledge.

brightness or lightness), all tend to treat the S-variable of saturation differently. It is judged in relation to either blackness (0 output in all RGB channels) or whiteness (maximum output in all RGB channels), but along different paths, depending on the shape of the HSV/L/B space in question.

3. CONCLUSION

The above are just a few of the examples of how misunderstandings can arise when talking about ‘light’ or ‘colour’ across disciplines. One of the greatest stumbling blocks is using the terms without reference to their context. Different applications and different modes of appearance of colour and light may require different terms and different definitions. The key to communication and understanding is in identifying the differences in conceptual approach. Only this way the wealth of knowledge about colour and light residing in the traditions of physics, psychophysics, perceptual experience and the various technologies will become fully available to research across disciplines. When speaking about human needs and endeavours in colour and light, the common denominator and final reference point for all the approaches is the human experience of ‘colour’ and ‘light’.

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