AIC 2004 Color and Paints

**Interim Meeting of the
International Color Association
Porto Alegre, Brazil, November 3-5, 2004**

Proceedings

edited by José Luis Caivano

2005

AIC 2004 "Color and Paints" was organized by the
Brazilian Color Association
(ABCor, Associação Brasileira da Cor)
on behalf of the
International Color Association
(AIC, Association Internationale de la Couleur)

AIC 2004 Color and Paints, Proceedings of the Interim Meeting of the International Color Association, Porto Alegre, Brazil, 3-5 November 2004

The proceedings include: invited lectures, oral papers, posters.

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Contents

Technology, Colorimetry, Order Systems

Architecture, Design, Arts, Aesthetics

Culture, Communication, Education

Closing session

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Program outline

TUESDAY, November 2		WEDNESDAY, November 3		THURSDAY, November 4		FRIDAY, November 5
	8:00 9:00	Registration – Posters hanging Opening ceremony	9:00 9:20 9:40 10:00	**Colored space & design** Guimarães Billger Hårleman Fridell Anter	9:00 to 10:20	Posters session
10:00 to 17:00 — AIC Executive Committee Meeting	10:00	**Osvaldo da Pos** Invited lecture (40')				
	10:40	Break (30')	10:20	Break (30')	10:20	Break (30')
	11:10 11:30 11:50 12:10	**Color perception** Zoido, Carreño, Bernabeu Sunaga, Yamashita Epps, Kaya Ohno	10:50 11:10 11:50	**Color education** Lewis Luzzatto, Pompas **Robert Hirschler** Invited lecture (40')	10:50 11:20 11:50	**Appearance & color differences** Ho, Cui, Luo, Rigg Duangmal et al. **Ronnier Luo** Invited lecture (40')
	12:30	Lunch (2 h.)	12:30	Lunch (2 h.)	12:30	Lunch (2 h.)
	14:30 14:50 15:10 15:30	**ECD, architecture** Ferring Mattiello Olsson Schindler	14:30 14:50 15:10	**Aesthetics & harmony** Stern Bavaresco Gurura, MacDonald, Dalke	14:30 14:50 15:10 15:30	**Colorimetry & textiles** Grancarić et al. Viková Gay, Melo, Hirschler Vik
	15:50	Break (30')	15:50	Break (30')	15:50	Break (30')
	16:20 16:40 17:00	**Architecture & landscape** Pogacar Cler Kjellström	16:20 16:40 17:00	**Order systems & paint** Holmberg, Nilsson Bergström Caivano, Menghi, Iadisernia	16:20 17:00	**Allan Rodrigues** Invited lecture (40') Congress closing AIC president P. Alessi
	17:20	Break (10')	17:20	**Roberto D. Lozano** Invited lecture (40')		
	17:30 17:50 18:10	**Color emotion** Stahre, Hårleman, Billger Kaya, Epps Sueeprasan et al.	18:00-19:00	Posters session — Study Group meeting		Tourism
	18:30 - 19:30	Posters session — Study Group meetings	20:00	Dinner barbecue		

Detailed program
(The presenting authors of oral papers are underlined)

TUESDAY, November 2, 2004

10:00 – 17:00 AIC Executive Committee Meeting

WEDNESDAY, November 3, 2004

8:30 Registration. Posters hanging

9:00 Reception and opening ceremony. Words of welcome: Hanns-Peter Struck (president of the ABCor), Paula J. Alessi (president of the AIC). Brief history of the AIC meetings: José L. Caivano (vice-president of the AIC)

Presentation of the next AIC Congress, Granada, Spain, 2005: Javier Romero (chairman of the organizing committee)

10:00 – 10:40 Invited lecture:

Chair: Karin Fridell Anter

Osvaldo DA POS **(Italy): When do colours become fluorent?**

10:40 – 11:10 Break (30 min.)

11:10 – 12:30 Color Perception:

Chair: Roberto Daniel Lozano

11:10 *Jesús ZOIDO, Fernando CARREÑO, and Eusebio BERNABEU* (Spain): A theory on color perception

11:30 *Shoji SUNAGA and Yukio YAMASHITA* (Japan): Evaluation of the color impression of colored texture patterns by a color naming method

11:50 *Helen H. EPPS and Naz KAYA* (USA): Color matching from memory

12:10 *Haruyo OHNO* (Japan): Color ratings for safety signs by young and elderly people

12:30 – 14:30 Lunch (2 hours)

14:30 – 15:50 Environmental Color Design, Architecture:

Chair: Maud Hårleman

14:30 *Mari FERRING* (Sweden): The colour-system of architectural structuralism: The office complex Garnisonen, Stockholm, Sweden

14:50 *María L. F. de MATTIELLO* (Argentina): Colour and light in architecture

15:10 *Gertrud OLSSON* (Sweden): Paul Scheerbart's utopia of coloured glass

15:30 *Verena M. SCHINDLER* (France): Prefabricated rolls of oil paint: Le Corbusier's 1931 *colour keyboards*

15:50 – 16:20 Break (30 min.)

16:20 – 17:20 Architecture and Landscape:

Chair: Monica Billger

16:20 *Vojko POGACAR* (Slovenia): Twelve-period seasonal colors-system

16:40 *Michel CLER* (France): Against colour globalisation. Colour trends and colour collections: Their use as a vocabulary and effect upon colour culture (presented by Verena Schindler)

17:00 *Richard KJELLSTRÖM* (Sweden): Local colouring and regional identity: Colours on buildings exterior

17:20 – 17:30 Break (10 min.)

17:30 – 18:30 Color Emotion:

Chair: Ana Maria Goron Tasca

17:30 *Beata STAHRE, Maud HÅRLEMAN, and Monica BILLGER* (Sweden): Colour emotions in larger and smaller scale

17:50 *Naz KAYA and Helen H. EPPS* (USA): Color-emotion associations: Past experience and personal preference

18:10 *Suchitra SUEEPRASAN, Pisut SRIMORK, Aran HANSUEBSAI, Tetsuya SATO, and Pontawee PUNGRASSAMEE* (Thailand and Japan): Quantitative analysis of Thai sensation on colour combination

18:30 – 19:30 Posters Session

18:30 – 19:30 Study Group Meetings:

Study Group on Color Education (Berit Bergström, chair)
Study Group on Color Perception of the Elderly (Manuel Melgosa, secretary)

THURSDAY, November 4, 2004

9:00 – 10:20 Colored Space and Design:

Chair: Hanns-Peter Struck

9:00 *Luciano GUIMARÃES* (Brazil): A model for application and analysis of the colors in the media
9:20 *Monica BILLGER* (Sweden): The experience of the painted room: The significance of light and colour combinations
9:40 *Maud HÅRLEMAN* (Sweden): Colour emotions in full-scale rooms
10:00 *Karin FRIDELL ANTER* (Sweden): Painted walls: From pictures and imitations to coloured space

10:20 – 10:50 Break (30 min.)

10:50 – 11:50 Color Education:

Chair: Berit Bergström

10:50 *Garth LEWIS* (England): Colour, painting and computing
11:10 *Lia LUZZATTO and Renata POMPAS* (Italy): Teaching color plans

11:50 – 12.30 Invited lecture:

Chair: Berit Bergström

Robert HIRSCHLER (Brazil): Light, colour, paints and pigments: A new concept in teaching colour for designers, architects and artists (presented by Mônica Araújo)

12:30 – 14:30 Lunch (2 hours)

14:30 – 15:50 Aesthetics and Harmony:

Chair: Osvaldo da Pos

14:30 *Claudia STERN* (Brazil): *Food for thought:* The use of color in sculpture
14:50 *Nelson BAVARESCO* (Brazil): Harmonic compositions of complementary colors according to their lightness degree
15:10 *Helen GURURA, Lindsay W. MACDONALD, and Hilary DALKE* (England): Background: An essential factor in colour harmony

15:50 – 16.20 Break (30 min.)

16:20 – 17:20 Order Systems and Paint:

Chair: Nick Harkness

16:20 *Kristina HOLMBERG and Anders NILSSON* (Sweden): What has made the use of NCS so widespread in the area of paint?
16:40 *Berit BERGSTRÖM* (Sweden): Aspects of colour communication between different paint materials
17:00 *José Luis CAIVANO, Ingrid MENGHI, and Nicolás IADISERNIA* (Argentina): Cesia and paints: An atlas of cesia with painted samples

17:20 – 18:00 Invited Lecture:

Chair: Nick Harkness

Roberto Daniel LOZANO (Argentina): Appearance in paints: Gloss, spatial filtering and definition of image (DOI)

18:00 – 19:00 Posters Session

18:00 – 18:30 Study Group Meeting:
Study Group on Environmental Color Design (José Luis Caivano, chair)

20:00 Dinner barbecue

FRIDAY, November 5, 2004

9:00 – 10:20 Posters Session

10:20 – 10:50 Break (30 min.)

10:50 – 11:50 Appearance and Color Differences:

Chair: Manuel Melgosa

10:50 *K. M. Raymond HO, Guihua CUI, <u>Ming Ronnier LUO</u>, and B. RIGG* (England): Assessing colour differences with different magnitudes

11:20 *<u>Kiattisak DUANGMAL</u>, Sekson WONGSIRI, and Suchitra SUEEPRASAN* (Thailand): Colour appearance of fruit juice affected by vitamin C

11:50 – 12.30 Invited lecture:

Chair: Manuel Melgosa

<u>Ming Ronnier LUO</u> (England): Verification of CIEDE2000 using industrial data *(in collab. with C. Minchew, P. Kenyon, G. Cui)*

12:30 – 14:30 Lunch (2 hours)

14:30 – 15:50 Colorimetry and Textiles:

Chair: Frank Rochow

14:30 *<u>Ana Marija GRANCARIĆ</u>, Tanja PUŠIĆ, Anita TARBUK, and Igor JANČIJEV* (Croatia): The fluorescence of sunprotected white cotton fabrics

14:50 *<u>Martina VIKOVÁ</u>* (Czech Republic): Visual assessment of UV radiation by colour changeable textile sensors

15:10 *<u>Jennifer Kathrin GAY</u>, Cássia Cristina MELO, and Robert HIRSCHLER* (Brazil): Instrumental whiteness evaluation: Practical results of inter-instrument agreement tests

15:30 *<u>Michal VIK</u>* (Czech Republic): Industrial colour difference evaluation: LCAM textile data

15:50 – 16.20 Break (30 min.)

16:20 – 17.00 Invited lecture:

Chair: Frank Rochow

<u>Allan RODRIGUES</u> (USA): Color technology and paint

17.00 Closing session:

Presentation of the AIC Congress 2009, Australia: Nick Harkness

<u>Paula J. ALESSI</u> (USA): Closing ceremony speech from AIC President

POSTERS EXHIBITED DURING THE WHOLE MEETING

1. Technology and Vision:

1.1. *Jaume PUJOL, Marta DE LASARTE, Montserrat ARJONA, Meritxell VILASECA, Francisco MARTINEZ-VERDÚ, Dolores DE FEZ, and Valentin VIQUEIRA* (Spain): Performance analysis of different optoelectronic imaging sensors for applications in color measurements

1.2. *Meritxell VILASECA, Jaume PUJOL, Montserrat ARJONA, Marta DE LASARTE, and Francisco MARTÍNEZ-VERDÚ* (Spain): Color visualization system for the discrimination of indistinguishable samples in the visible spectrum

1.3. *Javier ROMERO, Daniel PARTAL, Juan L. NIEVES, and Javier HERNÁNDEZ-ANDRÉS* (Spain): Looking for an invariant under daylight changes with L, M, S-type sensors

1.4. *Manuel SÁNCHEZ-MARAÑÓN, Rafael DELGADO, Encarnación GÁMIZ, Juan-Manuel MARTÍN-GARCÍA, Rafael HUERTAS, and Manuel MELGOSA* (Spain): Four soil color charts compared in CIELAB color space

1.5. *Kiattisak DUANGMAL, Busararat SAICHEUA, and Suchitra SUEEPRASAN* (Thailand): Roselle anthocyanins as a natural food colorant and improvement of its colour stability

1.6. *Marin MILKOVIC, Nina KNESAUREK, Nikola MRVAC, and Stanislav BOLANCA* (Croatia): Gamut characteristics of chromatic and identical desaturated achromatic reproductions

1.7. *Zdenka BOLANCA, Marin MILKOVIC, and Ivana BOLANCA* (Croatia): The permanence of conventional and digital offset prints

1.8. *Maja BROZOVIC and Nina KNESAUREK* (Croatia): Colorimetric investigations as quality criteria of the work of art reproductions

1.9. *Tomoko MIMA and Masako SATO* (Japan): Studies on ultraviolet-rays blocking by dyed fabrics: Comparison between direct dye/cellulose and disperse dye/polyester

1.10. *Boris SLUBAN and Olivera ŠAUPERL* (Slovenia): Target-position dependence of the effect of the proportional concentration errors for dyeing polyacrylic with basic dyes

1.11. *Djurdjica PARAC-OSTERMAN, Ana Marija GRANCARIĆ, and Ana SUTLOVIC* (Croatia): Influence of chemical structure of dyes on decolouration effects

1.12. *Djurdjica PARAC-OSTERMAN, Anica HUNJET, and Josip BURUSIC* (Croatia): Psychophysical study of colour

1.13. *María L. F. de MATTIELLO and Hugo SALINAS* (Argentina): Metamerism in the visual system

1.14. *Silvia PESCIO, María L. F. de MATTIELLO, and Ramiro ÁLVAREZ* (Argentina): Readability of chromatic documents

1.15. *José M. MEDINA, José R. JIMÉNEZ, Enrique HITA, and Luis JIMÉNEZ del BARCO* (Spain): Binocular stochastic models for suprathreshold chromatic changes at isoluminance

1.16. *Rafael HUERTAS, María José RIVAS, Ana YEBRA, María del Mar PÉREZ, Manuel MELGOSA, Manuel SÁNCHEZ-MARAÑÓN, and Enrique HITA* (Spain): Investigation of simulated texture effect on perceived color differences

1.17. *Ralph W. PRIDMORE and Manuel MELGOSA* (Australia and Spain): Effect of luminance on color discrimination ellipses: Analysis and prediction of data

1.18. *Jesús ZOIDO and Fernando CARREÑO* (Spain): Wavelength discrimination thresholds and psychophysical monochromaticity. Definition of the monochromaticity degree

1.19. *Hirohisa YAGUCHI, Naotaka WATANABE, and Satoshi SHIOIRI* (Japan): Effects of S-cone excitation on color discrimination threshold

1.20. *Lucia RONCHI and Niccolò ROSITANI* (Italy): Linking painting to visual science: Creativity versus quantification in the laboratory

Foreword

These Proceedings contain the full version of papers and posters presented at the Interim Meeting of the International Color Association (AIC, Association Internationale de la Couleur), carried out from November 3 to 5, 2004, in Porto Alegre, Brazil, on the theme of "Color and Paints". The congress was organized by the Brazilian Color Association (Associação Brasileira da Cor), and held at the Convention Center of the Pontificia Universidade Catolica de Rio Grande do Sul (PUCRS).

Initially, 104 abstracts were presented and accepted by the Scientific Committee: 6 invited lectures, 43 oral papers, and 56 posters. Finally, 74 papers were actually presented in the meeting: 5 invited lectures, 32 oral papers, and 37 posters. These are the ones published in this book, in addition to the closing speech delivered by the President of the AIC. The authors are representative of 16 countries: Argentina, Australia, Brazil, Chile, Croatia, Czech Republic, France, Italy, Japan, Slovenia, Spain, Sweden, Switzerland, Thailand, United Kingdom, and USA.

As it is usual at AIC interim and midterm meetings, the oral papers were organized in a single session, in order to avoid parallel speeches. The final program of the meeting is included in this book as a way of reflecting the arrangement of the presentations and some of the other main activities, such as meeting of the AIC Executive Committee, meetings of the AIC study groups, and social program (see pages vii-xii). Figure 1 shows a view of the room for the oral sessions, while Figure 2 shows some of the participants enjoying the delightful dinner barbecue accompanied with folkloric dances, which was sponsored by the NCS.

Figure 1. The room for the oral sessions, in the Convention Center of the PUCRS.

Figure 2. The dinner barbecue.

This Interim Meeting 2004 continues a long series of AIC congresses and meetings, which started in 1969, two years after the foundation of the AIC. Since 1977, the AIC has organized a congress or meeting every year, with the following structure: a full congress is held every four years, and three meetings (one midterm meeting and two interim meetings) are held in-between two successive congresses. The main difference among them is that full congresses are open to all topics and fields of color research, while interim and midterm meetings are concentrated upon more specific subjects. The chronology of congresses and meetings to date is as follows:

1969, June 9-13, 1st Congress, Stockholm, Sweden
1971, September 1-3, Special Symposium "Small Color Differences – Helmholtz Centenary", Driebergen, The Netherlands

1973, July 2-6, 2nd Congress, York, England
1976, June 8-11, Interim Meeting "Colour Dynamics", Budapest, Hungary

1977, July 10-15, 3rd Congress, Troy, New York, USA
1978, October 3-4, Interim Meeting "Color Measurement and its Application", London, England
1979, August 16-17, Midterm Meeting "Color Appearance", Tokyo, Japan
1980, February 3-6, Interim Meeting "Harry Helson Memorial Symposium on Chromatic Adaptation", Williamsburg, Virginia, USA

1981, September 21-25, 4th Congress, Berlin, Germany
1982, June 8-10, Interim Meeting "Colour Dynamics", Budapest, Hungary
1983, August 25-28, Midterm Meeting "Forsius Symposium Colour Order Systems", Kungälv, Sweden
1984, June 18-20, Interim Meeting "Colour Education", Salamanca, Spain

1985, June 16-22, 5th Congress, Monte Carlo, Monaco
1986, June 19-20, Interim Meeting "Color in Computer Generated Displays", Toronto, Canada
1987, June 10-13, Midterm Meeting "Wyszecki-Stiles Memorial Symposium on Color Vision Models", Florence, Italy
1988, August 8-11, Interim Meeting "Color in Environmental Design", Winterthur, Switzerland

1989, March 12-17, 6th Congress, Buenos Aires, Argentina
1990, September 2-5, Interim Meeting "Instrumentation for Colour Measurement", Berlin, Germany
1991, June 25-28, Midterm Meeting "Colour & Light", Sydney, Australia
1992, June 21-24, Interim Meeting "Computer Color Formulation", Princeton, New Jersey, USA

1993, June 13-18, 7th Congress, Budapest, Hungary
1994, April 10-12, Interim Meeting "Images in Colour", Cambridge, England
1995, September 3-6, Midterm Meeting "Colorimetry", Berlin, Germany
1996, June 15-18, Interim Meeting "Color & Psychology", Gothenburg, Sweden

1997, May 25-30, 8th Congress, Kyoto, Japan
1998, not held
1999, June 22-23, Midterm Meeting "Applications of Colorimetry in Industry and Design", Warsaw, Poland
2000, November 6-7, Interim Meeting "Color & Environment", Seoul, Korea

2001, June 24-29, 9th Congress, Rochester, New York, USA
2002, August 29-31, Interim Meeting "Color and Textiles", Maribor, Slovenia
2003, August 4-6, Midterm Meeting "Colour Communication and Management", Bangkok, Thailand
2004, November 2-5, Interim Meeting "Color and Paints", Porto Alegre, Brazil

Thus, this AIC 2004 meeting is Nr. 31 in the whole series.

   I wish to express my gratitude to the members of the Scientific Committee, who helped in shaping the theme and sub-themes of the meeting and made a very good job in reviewing all the abstracts presented, and my sincere congratulations to the members of the Organizing Committee for the success of the meeting.

José Luis Caivano
Chairman, Scientific Committee AIC 2004
Vice-president, AIC

PERCEPTION, PSYCHOLOGY,
PSYCHOPHYSICS, VISION

When do colours become fluorent?

Osvaldo DA POS

Department of General Psychology, University of Padua

ABSTRACT

Evans (1949) realised that physical fluorescence is neither sufficient nor necessary for producing the correspondent colour appearance, which can be generated by only increasing the luminance of a surface beyond a certain level. He called fluorence the perceptive phenomenon and fluorent the colours. Three experiments were performed to find the luminance threshold of the four unique hues to appear fluorent over either a uniform white background or a coloured Mondrian, by using the limits and staircase method. Results show that yellow has a threshold around the luminance of the surface white (sometimes higher), significantly higher than the threshold for the green, which is still significantly higher than that of the blue and red; moreover there is a significant inverse correlation between threshold and chromaticness. A fourth experiment shows that the threshold of reddish and greenish colours increases as a function of yellowness. Theoretical consequences dealing with the structure of colour systems are proposed.

1. INTRODUCTION

R. Evans (1949, 1959, 1974) was the first to perform a systematic study of fluorent colours. He realised that no physical fluorescence but simple luminance relationships between colours are the essential conditions to evoke the correspondent impressions. He called fluorence this effect to distinguish it from the physical process, and considered it of the greatest importance in developing a new approach to colour theory. Fluorence would be an intermediate step between surface and luminous colours along a continuum called brilliance. The lower branch of this continuum is characterised by a grey appearance, correlated with the visual impression of reflected light, which decreases from black to lighter colours until it completely disappears ad a point called zero greyness. Where greyness ends, fluorence starts. Greyness would be then a specific aspect of surface colours corresponding to the blackness of the Natural Colour System (Hering 1874; SIS 1989). Primarily concerned with the theory, Evans analysed relatively few colours, and until now, except few works (for instance by Bonato and Gilchrist 1994; Petrov et al. 1998), little research has been carried out in the field. This investigation presents a systematic study of the luminance threshold separating surface from fluorescent colours.

2. EXPERIMENT 1

The aim of this experiment was to determine the luminance thresholds separating surface from fluorent colours.

2.1 Material and method

The apparatus used in all the four experiments of this research was devised to approximately replicate the viewing conditions of Evans work. The background against which the fluorent surface had to be seen was made of an A4 white cardboard (at a luminance of about 55 cd/m^2), subtending 9.5° × 6.8° at a viewing distance of cm 177, vertically placed in a completely black and dark box, and uniformly lighted by a couple of D65 simulators at about 175 lux.
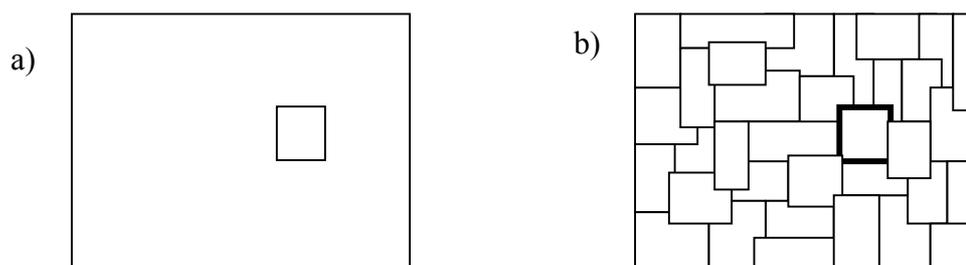
Figure 1. Position of the coloured target in the background: a) uniform white(experiment 1 and 4); b) coloured Mondrian (experiment 2, 3, and 4).

The target area (see Figure 1a) was a small rectangular hole of cm 4 × 6 (subtending 1.3° × 2°), through which an independently lit coloured paper placed 15 cm behind the background, at 45° as respect to its plane, could be seen. Twelve different coloured papers were used in experiment 1 (Table 1), taken from the four unique hues of the NCS collection (2nd edition) at the least possible degree of blackness. The independent illumination was provided by a D65 simulating lamp mounted on a rail perpendicular to the coloured paper and could be moved back and forth along the rail either by the observer or by the experimenter to vary with continuity the luminance of the target. The luminance of all colours was measured after each trial by an UDT150 Photometer placed at the same position of the observer's eye.

*Table 1. Coloured samples used in experiment 1 (*NCS 3rd edition).*

NCS notation			
00 40 Y	00 40 R	10 40 B	10 40 G
00 60 Y	05 50 R*	10 50 B	10 50 G
05 80 Y*	05 65 R*	10 70 B	10 70 G

Twelve psychology students, with normal colour vision, volunteered as subjects. Before the beginning of the experiment each observer was shortly trained to distinguish the surface from the fluorent mode of colour appearance. He was instructed to move back and forth the sliding lamp (hidden behind a black wall) by means of two strings to change the luminance, and consequently the appearance, of the target area from a clearly surface to a clearly fluorent mode of appearance. The experimental task consisted in finding the threshold between the surface and fluorent mode for all the 12 colours (presented in random order) by the psychophysical method of limits. The different luminance steps were produced by the experimenter, who each time noted down whether the target appeared of a surface or fluorent mode to the observer. Four runs, with different starting points, were made for each colour.

2.2 Results and discussion

Results are shown in Figure 2. The luminance threshold dividing the surface from the fluorent appearance of the 12 tested colours differs as a function of the hue and of the NCS chromaticity, showing that a yellow target appears fluorent at a luminance closed to that of the surface white, while green, blue and red targets appear fluorent at lower and lower luminance. The luminance needed to appear fluorent is also lower for more chromatic colours.
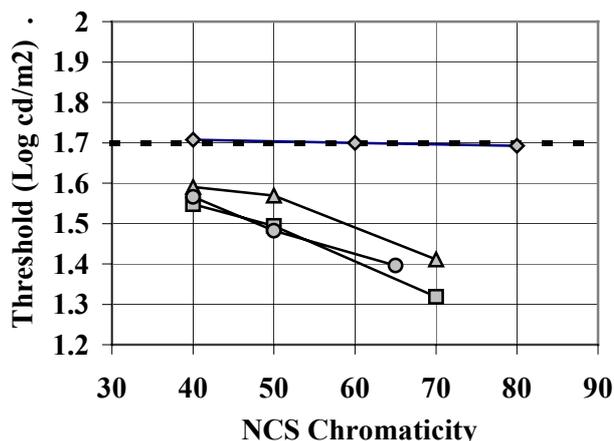
Figure 2. Luminance threshold of the four unique hues for appearing fluorent as a function of their chromaticity. Diamond: yellow; square: blue; triangle: green; circle: red. Dotted line: luminance of the surface white.

In general the fluorence threshold is always at a lower luminance than that of the surface white, except for the yellow which appears fluorent at around the same luminance of the surface white, and significantly higher ($F_3 = 71.86$, $p < 0.00001$) than that of the other three hues. Fluorence threshold decreases significantly ($F_2 = 40.06$, $p < 0.0001$) when NCS chromaticity increases (except between the first two levels). The shape of the threshold curves as a function of the NCS chromaticity is strictly similar to that found by Evans as a function of Munsell chroma, and probably delineates the outer surface of the optimal colour solid.

3. EXPERIMENT 2 AND 3

The aim of these experiments was to check whether fluorence thresholds are influenced by figural and chromatic complexity of the background (a coloured Mondrian instead of a uniform white).

3.1 Material and method

The same apparatus as in experiment 1 was used. The background is a coloured Mondrian instead of a uniform white surface (Figure 1b). Around the hole, which is assuming different hues during the experiment, are placed different greys, while the rest of the background is covered with different nuances of the four unique hues, about 40 in all.

Twenty-two psychology students with normal colour vision volunteered in experiment 2 and other 12 on experiment 3. The psychophysical procedures were the method of limits in experiment 2 and a simple staircase method in experiment 3.

3.2 Results and discussion

Results are plotted in Figure 4a (experiment 2) and 4b (experiment 3), and look very similar to those of experiment 1, with the exception that thresholds are generally higher.
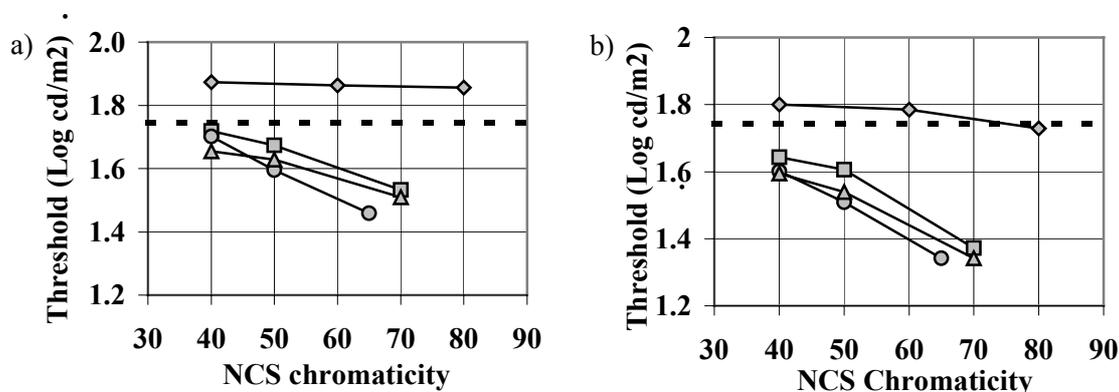
Figure 4. Threshold of the four unique hues for appearing fluorent as a function of their chromaticity when the background is a coloured Mondrian. Methods: limits (a), staircase (b). Diamond: yellow; square: green; triangle: blue; circle: red. Dotted line: luminance of the surface white.

In experiment 2, the luminance necessary for making the yellow fluorent is much higher than that of the surface white. All hues show significantly different thresholds ($F_3 = 43.72$, $p < 0.0001$), except between red and blue. Fluorence, which makes the colours to pop out from a set of surface colours, seems to require higher luminance when the background is more complex in shape and colour, as in the case of the coloured Mondrian as compared with a uniform white surface. Lastly, here too thresholds significantly decrease ($F_2 = 13.02$, $p < 0.0001$) when NCS chromaticity increases. In experiment 3, still all hues show significantly different thresholds ($F_3 = 134.12$, $p < 0.00001$) with the expected exception of red and blue; moreover thresholds significantly decrease as the NCS chromaticity increases ($F_2 = 322.45$, $p < 0.00001$).

4. EXPERIMENT 4

The aim of this experiment was to check whether fluorence thresholds increase as a function of yellowness in reddish and greenish yellows. On the basis of the previous results higher thresholds were expected for greenish than for reddish colours.

4.1 Material and method

The same apparatus was used as in the previous experiment. The list of target colours for which the fluorence threshold was found is given in Table 2. The background was either a uniformly white surface, or the coloured Mondrian previously described. 10 psychology students with normal colour vision took part in the experiment; a simple staircase method was used.

Table 1. Coloured samples used in experiment 4.

NCS notation						
00 60 Y20R	0060 Y40R	0070 Y60R	0060 G80Y	0060 G60Y	0060 G40Y	05 00 N

4.2 Results and discussion

Results are shown in Figure 6. As yellowness increases, also thresholds significantly increase, as expected (F_2 = 27.92; p < 0.0001). Greenish colours have significantly higher thresholds than the reddish ones (F1 = 200.65, p < 0.0001). Thresholds do not differ as a function of the background.
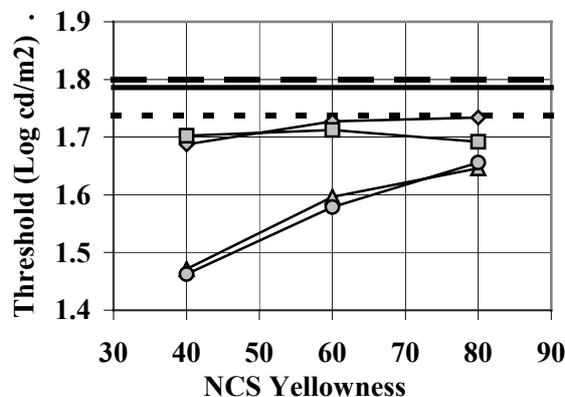
Figure 6. Luminance threshold of three yellowish hues for appearing fluorent as a function of their yellowness. Diamond: greenish hue on a Mondrian; square: greenish hue on white; triangle: reddish hue on a Mondrian; circle: reddish hue on white. Dotted line: surface white. Broken line: fluorence threshold of white on a Mondrian. Continuous line: fluorence threshold of white on uniform white.

The white target becomes fluorent at a relatively low luminance level; both thresholds significantly differ from the luminance of the surface white (t = 2.32, p = 0.045 on the white background; t = 4.16, p = 0.002 on the coloured Mondrian).

5. CONCLUSION

Results of all experiments show that yellow has a very high fluorence threshold, near to or higher than the luminance of the surface white, and is followed by green which still shows higher thresholds than red and blue; on the other hand the thresholds of these last hues are never different. We cannot but thinking that fluorence threshold is proportional to the natural lightness of hues (this can be revealed by looking at the highest chromatic nuance of a particular hue): while among all hues the natural lightness of yellow is the highest followed by that of green, those of red and blue are lower and almost of the same level, being higher only to that the purple. Moreover it is well known that a yellowish white appear darker than a bluish white of the same luminance, and this might account for the proximity, or even superiority, of the fluorence threshold of yellow to the luminance of the surface neutral white.

The decrease of fluorence thresholds as a function of chromaticness is a common feature of all our results and is theoretically relevant in the organisation of a colour system. On the one side it may reflect the Helmholtz-Kohlrausch-Boswell effect (da Pos and Zambianchi 1996) which makes high chromatic colours look brighter; on the other side it shows that lightness and greyness (or blackness) do not refer to the same colour variable, as their functions are different.

Already Evans (1959) noted that in the Munsell System greyness curves are not parallel to the lightness functions (Figure 7): if a colour solid were enclosed by the surface corresponding to zero greyness colours, its shape would be roughly conical (somehow as in

the Natural Colour System, although irregular) rather than cylindrical (as theoretically in the Munsell System). This poses the question of which visual attributes are more relevant in describing the surface colours as they appear to the observer. The acceptance of the brilliance dimension as a fundamental variable in colour perception, in addition to agree with the proposals by Hering expressed in the NCS, would make it possible to build a colour system that can be extended from surface to luminous colours passing through the fluorent ones.
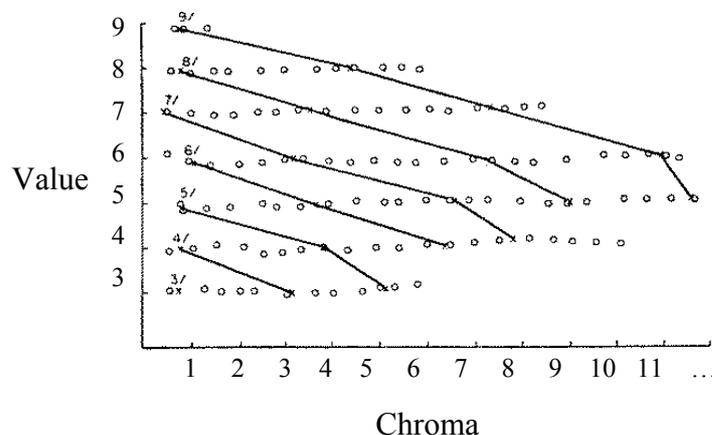
Figure 7. Samples along any curve were judge to have the same grey content (from Evans, 1959). Red on white background.

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A theory on color perception

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ABSTRACT

In this contribution a theoretical model of the color perception process is proposed. It is assumed that any spectral power distribution belongs to the Hilbert space of continuous functions over the visible spectrum. In order to introduce a topology which allows us to generalize all the concepts of the Euclidean geometry, this space is endowed with the natural inner product. Orthogonality plays a major role in the proposed model. The concept of metamerism can be interpreted as a relation of equivalency. The detection process can be decomposed in two different steps. A matrix T, characterizing the colorimetric behavior of a given observer is defined. The property of invariance associated with the inverse matrix T^{-1} suggests the generalization of the trichromatic equation. We propose a redefinition of the concepts of radiant flux and luminous efficiency.

We have experimental evidence that any color stimulus $\vec{X}$ can be matched by the additive mixture in suitable amounts of three physical light stimuli $\vec{u}_i$ (i=1, 2, 3), termed primaries. Thus, the following equation can be written to characterize a color matching experiment:

$$\vec{X} = \sum_{i=1}^{3} X_i \vec{u}_i, \tag{1}$$

where tristimulus values X_i represent the amounts of the primaries required for a match. Any color stimulus can be represented by a vector of $\Re^3$, $\vec{X} = (X_1, X_2, X_3)^t$, whose coordinates in the basis $B_c = \{\vec{u}_1, \vec{u}_2, \vec{u}_3\}$ are given by the tristimulus values. Expression (1) is usually known as trichromatic equation.

The spectral tristimulus values obtained when all the monochromatic stimuli with unit radiant power are matched in equation (1) are known as color-matching functions, $\hat{e}_i(\lambda)$. Color-matching functions can be transformed into a new set of functions where the primaries are imaginary. There is a set for which each curve is proportional to the spectral sensitivity of one of the three kinds of retinal receptors. We will refer to $\hat{e}_i(\lambda)$ function as the curve of spectral sensitivity associated with the i-*th* retinal receptor. When a spectral power distribution impinges on the visual system, the tristimulus values in expression (1) are given by $X_i = K \int_{\chi} \hat{e}_i(\lambda) n(\lambda) d\lambda$, χ being the wavelength interval within the visible spectrum, and K is a constant depending on the set of primary stimuli in which the color-matching functions are expressed. In this way quantity X_i can be interpreted as the signal provided by the i-*th* receptor when it is excited by the distribution $n(\lambda)$.

When considering a new set of primary stimuli $\vec{u}_i'$, such that $\vec{u}_i = \sum_{j=1}^{3} c_{ji} \vec{u}_j'$, the tristimulus values X_i measured in terms of the original set of primary stimuli and those, X_i',

measured in terms of the new set of primary stimuli, are related by transformation $\vec{X}' = C\vec{X}$, with matrix $C = \{c_{ij}\}$, and $\vec{X}' = (X_1', X_2', X_3')^t$ being the coordinates of the color stimulus in the new basis $B_c' = \{\vec{u}_1', \vec{u}_2', \vec{u}_3'\}$. Color-matching functions $\hat{e}_i'(\lambda)$ referred to the new set of primary stimuli are given by $\vec{e}' = C\vec{e}$, where $\vec{e} = (\hat{e}_1(\lambda), \hat{e}_2(\lambda), \hat{e}_3(\lambda))^t$ and $\vec{e}' = (\hat{e}_1'(\lambda), \hat{e}_2'(\lambda), \hat{e}_3'(\lambda))^t$.

Let us consider a spectral power distribution $n(\lambda) \in L_\chi^c$, where L_χ^c is the Hilbert space of continuous functions over the interval χ. We will assume that a certain distribution $n(\lambda)$ belongs to a subspace L_χ included in L_χ^c ($n(\lambda) \in L_\chi \subset L_\chi^c$). The dimension Q of this subspace is finite but large enough.

Space L_χ^c is endowed with the natural inner product defined as usually by

$$\langle n_1(\lambda), n_2(\lambda) \rangle = \int_\chi n_1(\lambda) n_2(\lambda) d\lambda. \tag{2}$$

Thus, two functions $n_1(\lambda)$ and $n_2(\lambda)$ which belong to L_χ^c satisfy the orthogonality condition when $\langle n_1(\lambda), n_2(\lambda) \rangle = 0$. The norm of $n(\lambda)$ is defined in the usual way as $\|n(\lambda)\| = \langle n(\lambda), n(\lambda) \rangle^{1/2}$. Thus, the distance between two distributions is given by $d[n_1(\lambda), n_2(\lambda)] = \|n_1(\lambda) - n_2(\lambda)\|$.

It will be assumed that color-matching functions $\hat{e}_i(\lambda)$ also belong to the subspace L_χ. From definition (2), it becomes obvious that these functions are linearly independent, in such a way that they generate de three-dimensional subspace $D_3 = lin\{\hat{e}_1(\lambda), \hat{e}_2(\lambda), \hat{e}_3(\lambda)\} \subset L_\chi$, and $B_e = \{\hat{e}_1(\lambda), \hat{e}_2(\lambda), \hat{e}_3(\lambda)\}$ is a basis of D₃. We will refer to this subspace as *detection space*. When considering the set of primary stimuli $\vec{u}_i'$, the set $B_e' = \{\hat{e}_1'(\lambda), \hat{e}_2'(\lambda), \hat{e}_3'(\lambda)\}$ is also a basis of D₃.

For a given distribution $n(\lambda)$, the signal provided by the i-*th* detector can be rewritten as

$$X_i = K \langle \hat{e}_i(\lambda), n(\lambda) \rangle. \tag{3}$$

The subset R={ $\vec{X} = (X_1, X_2, X_3)^t$, such that $X_i = K \langle \hat{e}_i(\lambda), n(\lambda) \rangle$ for all $n(\lambda) \in L_\chi$}, included in $\Re^3$, which contains all the possible sets of tristimulus values perceived by the visual system, will be called *representation system*.

The color perception process can be mathematically described by the *detection application* $D : L_\chi \to R$, such that $D[n(\lambda)] = \vec{X}$.

An important property of this application is the following one: condition $n_1(\lambda) \neq n_2(\lambda)$ does not imply condition $D[n_1(\lambda)] \neq D[n_2(\lambda)]$, thus D is not an injection. This property points out how the metamerism can be formally described by a relation of equivalency: all the functions providing the same color sensation $\vec{X}$ are contained in the equivalence class C_X={ $n(\lambda) \in L_\chi$, such that $D[n(\lambda)] = \vec{X}$ }.

Any arbitrary function $n(\lambda) \in L_\chi$ can be uniquely represented in the form

$$n(\lambda) = n^D(\lambda) + n^{D\perp}(\lambda), \tag{4}$$

$n^D(\lambda)$ being the orthogonal projection of $n(\lambda)$ onto D_3, and $n^{D_\perp}(\lambda)$ is the corresponding projecting function, which belongs to the orthogonal complement, $D_3^\perp$, of the detection space. Condition $\langle n^D(\lambda), n^{D_\perp}(\lambda)\rangle = 0$ is satisfied. This fact allow us to rewrite signals (3) as

$$X_i = K\langle \hat{e}_i(\lambda), n^D(\lambda)\rangle. \tag{5}$$

Expression (5) points out how the orthogonal projection $n^D(\lambda)$ alone is the cause of the color sensation and the projecting function has no effect whatever on the evoked color sensation. In this way, the visual system only processes the function $n^D(\lambda)$, which contains all the useful information. This fact suggests us to refer to this function as *processing information*. Expression (5) allows us to simplify the formal description of the color perception process by considering function $n^D(\lambda)$, belonging to a three-dimensional space, instead of function $n(\lambda)$, which belongs to a Q-dimensional space.

From this analysis, the color perception process can be decomposed in two different stages. In the first of them, the processing information is extracted from $n(\lambda)$ and we will refer to it as *discrimination process*. This stage can be formally described by the *discrimination operator*, $P_r : L_\chi \to D_3$, which is the orthogonal projection operator of subspace L_χ onto the subspace D_3, given by $P_r[n(\lambda)] = n^D(\lambda)$. Taking into account the properties of the norm defined from (2) and decomposition (5) we obtain the following relation:

$$\|P_r[n(\lambda)]\| = \|n^D(\lambda)\| \le \|n(\lambda)\|. \tag{6}$$

Inequality (6) guarantees the existence of an image for any $n(\lambda) \in L_c$.

The second stage in the color perception process is the *processing* step. In this stage the information contained in $n^D(\lambda)$ is processed providing the corresponding tristimulus values. This step is described by the *processing application*, $P : D_3 \to R$, such that $P\lfloor n^D(\lambda)\rfloor = \vec{X}$. Application P is a non-singular one, thus there exists an isomorphic relation between spaces D_3 and $\Re^3$. This relation confirms how the discrimination operator optimizes the information processed in the last stage by the visual system. The detection application can be rewritten as the composition of the processing application and the discrimination operator as $D = P \circ P_r$.

Let w_i be the coordinates of $n^D(\lambda)$ in the basis B_e of D_3. The processing information can be written in matrix form as

$$n^D(\lambda) = \sum_{i=1}^{3} w_i \hat{e}_i(\lambda) = \vec{e}^{\,t}\vec{w}, \tag{7}$$

with $\vec{w} = (w_1, w_2, w_3)^t$. We replace tristimulus values (5) in expression (1) and, by using (7), the action of the processing application on the processing information is given in matrix form by

$$\vec{X} = T\vec{w}, \tag{8}$$

with $T = \{t_{ij}\}$, and $t_{ij} = K\langle \hat{e}_i(\lambda), \hat{e}_j(\lambda)\rangle$. Matrix T is a symmetric one and it represents to the processing application when bases B_e in D$_3$, and B_c in $\Re^3$ are considered. This matrix depends on the color-matching functions of the considered observer. For this, we will refer to it *as characteristic matrix*. If basis B_c' is considered, the characteristics matrix T' associated with the new set of primaries $\vec{u}_i'$ satisfies the following relation:

$$T' = CTC^t. \tag{9}$$

Inverting expression (8) and replacing this result in equation (7), the processing information can be rewritten in terms of the tristimulus values in the form

$$n^D(\lambda) = e^t T^{-1} \vec{X} . \tag{10}$$

When the set of primary stimuli $\vec{u}_i'$ is considered, the processing information referred to the basis B_c' will be given by $n^D(\lambda)' = (e')^t (T')^{-1} \vec{X}'$. By introducing in this expression the matrix C, which provides the change of tristimulus values (or color-matching functions), and equation (9), we obtain, when comparing with (10), $n^D(\lambda)' = n^D(\lambda)$. This important result points out that processing information is independent on the set of primary stimuli, i.e., it is invariant under linear transformations of the representation system.

Let $s_i(\lambda) \in D_3$ be the processing information associated with the i-*th* primary stimulus. It can be demonstrated that relation $\vec{e} = T\vec{s}$ holds, with $\vec{s} = (s_1(\lambda), s_2(\lambda), s_3(\lambda))$. From this expression, and equations (7) and (8) we have $n^D(\lambda) = \vec{s}^t \vec{X}$, i.e.,

$$n^D(\lambda) = \sum_{i=1}^{3} X_i s_i(\lambda). \tag{11}$$

This equation characterizes a color matching experiment in the detection space. Distribution $n^D(\lambda)$ is expressed in terms of the non variable functions $s_i(\lambda)$. It should be noted that coordinates X_i in the trichromatic equation (1) have units of amount of light, while the same coordinates in (11) are non dimensional quantities. This fact together the property of invariance suggests that equation (11) can be used in order to characterize a color matching experiment in the detection space, instead of doing it in the color representation system by using the trichromatic equation (1).

The radiant flux of a certain distribution n(λ) is defined as $\Phi_l = \int_\chi n(\lambda) d\lambda$. However decomposition (4) does not guarantee that $n(\lambda) > 0 \quad \forall \quad \lambda \in \chi$. Thus, we recur to the norm in order to introduce the concept of *generalized radiant flux* as $\Phi_{rg} = \|n(\lambda)\| = \left(\int_\chi n^2(\lambda) d\lambda \right)^{1/2}$. The previous definition is consistent with the units of the usual magnitude of radiant flux. It is easy to show that $\Phi_{rg} \geq \Phi_{rg}{}^D = \|n(\lambda)\|$. The last inequality indicates that the orthogonal projection $n^D(\lambda)$ is the element of the equivalence class C_X with the minimum generalized radiant flux. In this sense $n^D(\lambda)$ is the most efficient element of C_X.

In a similar way, the luminous flux is determined as $\Phi_l = K \int_{\lambda_1}^{\lambda_2} n(\lambda) V(\lambda) d\lambda$, V(λ) being the luminous efficiency of the visual system. Note that the usual notion of luminous efficiency is the quotient between the luminous flux to the radiant flux. Thus we propose a redefinition of the luminous efficiency as $E_{fg} = k_{ef} \Phi_l / \Phi_{rg}$, k_{ef} being a constant used for normalization purposes.

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Evaluation of the color impression of colored texture patterns by a color naming method

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ABSTRACT

We investigated the Munsell-hue ranges in which a single color impression as a whole could be sensed in multi-colored textures, by using random-dot texture patterns made by two kinds of colored dots with different Munsell-hue and constant Munsell-value (V=5/) and -chroma (C= /6). Observers reported first whether a single color impression as a whole was perceived in them or not. In cases they perceived a single color impression, they also responded the received color name by a color naming method. The results showed that the single color impression could be perceived for color combinations within a hue difference ΔH_{min} of 23 (for SS) or 14 (for MS), which was independent of those color combinations. The extent of color combination in which a single color impression was perceived exceeded the range of a categorical color. Many color combinations induced the perception of a single color impression, even when the two colors were included in different categorical colors. When the two colors were on an identical tritanopic confusion line, a single color impression was sometimes reported even when the two colors were complementary colors to each other. This suggests that the low visual resolution of textured colors might promote the production of single color impression as a whole.

1. INTRODUCTION

An additive color mixture by spatial arrays of tiny areas with different colors is a useful technique of color reproduction in the field of textile, art, and engineering, etc. When each colored element is sufficiently small to be indistinguishable, the chromaticity of the color perceived in the multi-colored texture pattern is almost equal to the colorimetric average of those colored elements. However, when the elements have a size large enough to be distinguished and have similar colors, a single color impression unlike the average as a whole is often sensed in them. In this case, it is not known how such a color impression is determined from the elements' colors in the texture. Sunaga and Yamashita (2003) reported the single color impression of two-colored texture patterns made by elements with different saturations and an identical unique hue and equal brightness. They showed that the chromaticities of the single color impression were on the bent unique hue loci and shifted towards a more saturated color between two element colors. It was suggested that the color of the impression was not a colorimetric average and might be determined by a color mechanism for integrating color appearance of the elements' colors. The mechanism determining a single color impression of a multi-colored texture pattern is not well known yet.

In this study, we used a texture pattern made by two Munsell-hue elements and measured the range of hue difference in which a single color impression was sensed by a color naming method. We called the hue difference ΔH. In addition, we examined whether the range of perceived colors could be limited to a categorical color of the two elements' colors or not.

2. METHODS

2.1 Stimuli

Colors simulating the Munsell colors were generated on a CRT display controlled by a personal computer. We assumed a displayed white of D65 chromaticity and luminance of 70.0 cd/m^2 as a standard white by a perfect reflected diffuser illuminated by D65 light. The stimulus was a random-dot texture pattern of 4 deg × 4 deg square made by two colored elements of 4 min × 4 min square as shown in Figure 1. It was surrounded by a uniform N6 gray square of 12 deg × 12 deg and a N9 white band of 30 min width. The element's size was large enough to be distinguished. The ratio of the number of the two colors was 50% vs. 50%.

One of the two colors of the texture pattern was chosen from 10 colors of the major hue: 5R, 5YR, 5Y, 5GY, 5G, 5BG, 5B, 5PB, 5P, and 5RP. We called this color an anchor test color. The other color was chosen from 20 hues of every five-hue interval, i.e. 5 and 10 of each Munsell-hue. The Munsell-value and the Munsell-chroma of these colors were constant: V= 5/ and C= /6. We had 115 conditions of color combination.
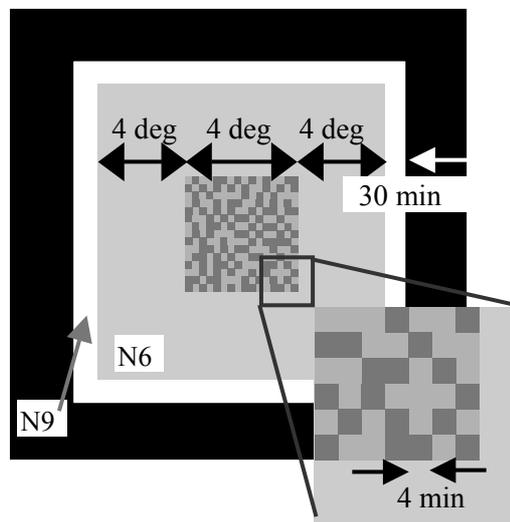
Figure 1. The random-dot texture pattern used as a stimulus.

2.2 Procedure

Before starting the measurement, observers adapted to the dark display for 5 minutes and then adapted to the gray surround with the white band for 2 minutes. The gray surround and the white band were always displayed during the experiment. The texture pattern of 115 color combinations was presented in random order on the center of the gray surround for 1 second.

Observers reported first whether a single color impression as a whole was perceived in the pattern or not. Then, if they perceived a whole color impression, they answered the name of the sensed color by a color naming method out of one of the following 13 colors: red, orange, yellow, yellow-green, green, blue-green, blue, purple, pink, brown, white, gray, and black. The observer performed 20 trials for the combinations of the 10 major hues and 10 trials for the combinations with other hues.

Two observers (MS, a female, and SS, a male) participated in the experiment. They had normal color vision and normal or corrected-to-normal acuity. SS was one of the authors and MS was naïve on the purpose of the experiment.

3. RESULTS

Figure 2 shows a part of the results for the two observers. Each panel indicates the results for the combination of different anchor test colors. The horizontal axis indicates the other hue combined with an anchor test color. The vertical axis represents the probability of perception of a single color impression as a whole and that of the color reported in the color naming
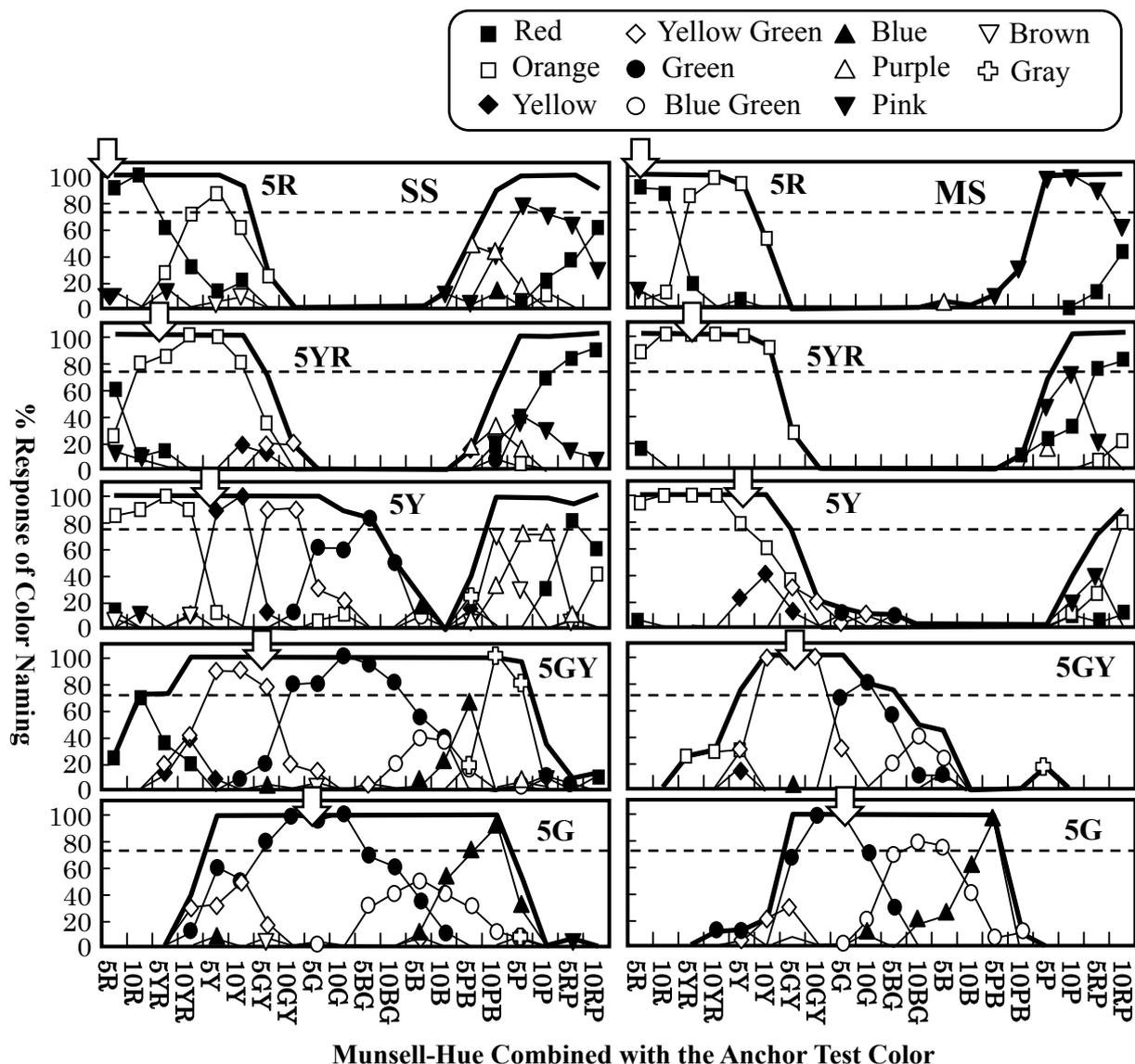
Figure 2. Probabilities of the perception of a single color impression and their colors. Dashed lines indicate 75%. Left panels are data for observer SS and right panels are for observer MS. Arrows show the anchor test color.

method. Thick solid lines show the probabilities of perception of a single color impression for various color combinations. Different symbols represent the probabilities of colors sensed as a single color impression. Arrows of the upper part of each panel indicate the horizontal positions of the anchor test colors.

The single color impression was obtained for the color combinations with neighboring colors of the anchor test color. The extent of color combinations in which a single color impression were obtained depended on the Munsell-hue of the anchor test color. Even in the complementary color combination, the single color impression as a whole was reported as the results for 5GY and 5P for SS. The cause of this can be attributed to the fact that those colors were on an identical tritanopic confusion line. There were some individual differences in some hue combinations, especially for the anchor test colors of 5Y, 5GY, 5PB, and 5P (the results of 5PB and 5P are not shown in Figure 2).

4. DISCUSSION

We calculated the Munsell-hues that provide 75% of the perception of a single color impression in order to estimate the hue difference (ΔH) able to produce a single color impression as a whole. The ΔH are shown in Figure 3. The horizontal axis indicates the anchor test color in the texture pattern. The vertical axis indicates ΔH. Open symbols are ΔH of clockwise direction in the Munsell-hue circle, and closed symbols are ΔH of counterclockwise direction.

The ΔH modulated with the anchor test colors and had a resembling tendency for both observers. The ΔH modulation of the counterclockwise direction had maxima at 5Y and 5PB, and minima at 5GY and 5PR. The ΔH curves of the clockwise direction had maxima at 5GY or 5G and 5P or 5RP, and minima at 5YR or 5Y and 5B or 5PB.

The following two points seem to be causes of the modulation of ΔH. First, if the color appearance based on the opponent colors contributed to the single color impression, the disagreement between the opponent color system and Munsell-hue circle may have reflected the magnitude of ΔH depending on the anchor test color. Second, the visual resolution may have affected the perception of single color appearance of the color texture, resulting in larger ΔH. This hypothesis may be supported by the result of the color combination of 5GY 5/6 and 5P 5/6. Since those colors were complementary but on an identical tritanopic confusion line, the border between them was thought to have melted. Indeed, both observers reported that not only yellow-green and purple but also gray were seen in some places of the pattern. Observer SS in fact could perceive the whole color impression as gray in this color combination. Thus the production of a single color impression seems to depend on the visual resolution as well as the element colors.

The dashed lines in Figure 3 represent ΔH_{min}, which is the average of some minima ΔH. The ΔH_{min} represents the maximum hue difference that generated the whole color impression independent from the color combination. The value of ΔH_{min} was 23 for SS, and 14 for MS.

Next, we discuss the relationship between the categorical color of a whole color impression and the categorical colors of the texture elements. Figure 4 shows the results of

Munsell-Hue of the anchor test color in texture element
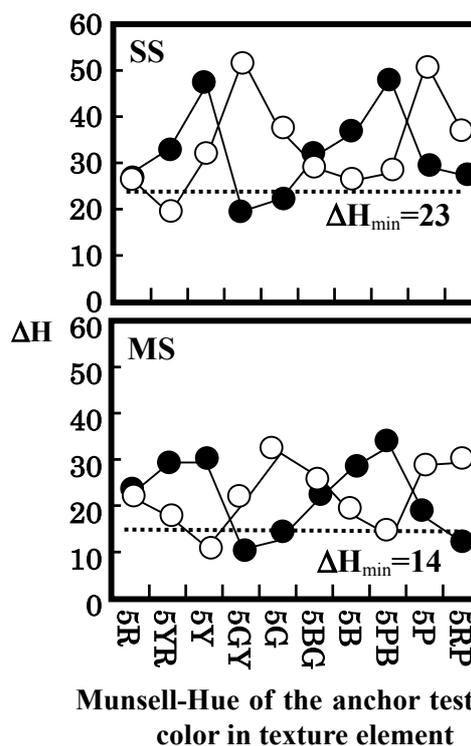
Figure 3. The results of ΔH for the colored texture pattern.
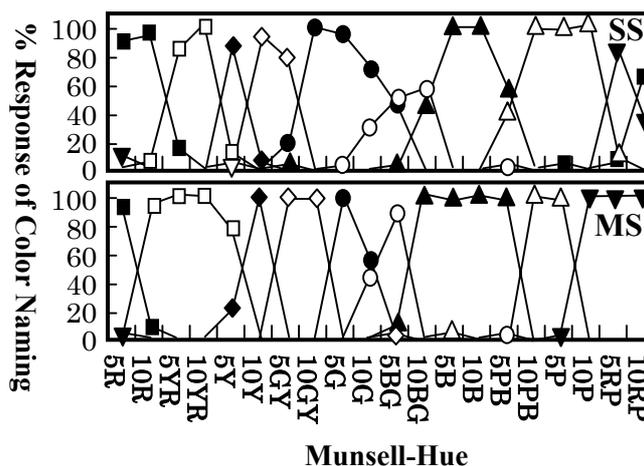
Munsell-Hue

Figure 4. Results of the color naming for Munsell-hues. Different symbols show the same colors as those in Figure 2.

color naming for a uniform field of each Munsell-hue used in the experiment. It is clear that the obtained extent of the perceived single color impression is wider than that of the categorical color of each anchor test color, when we compare Figure 2 and Figure 4. The production of single color impression was not restricted to the categorical color of the anchor test color. The combination with the colors belonging to the different categorical colors could produce a single color impression as a whole. There was a case in which the color combination of different categorical colors made a single color impression of the third categorical color. For example, the combination of 5R of the category "Red" and 5Y of the category "Yellow" produced the color impression of "Orange". For MS, a single color impression was produced in the combination of 5P and 10PB belonging to the same category of "Purple" and that of 5R and 5P, but not in 5R and 10PB. That is, even if an anchor test color was combined with the colors belonging to same color category, there were cases in which the single color impression was obtained and cases in which it was not obtained. This tendency was also observed among other color combinations. This suggests that a single color impression of a multi-colored texture pattern is not determined in the stage of categorical color perception.

5. CONCLUSIONS

We measured the extent of hue difference (ΔH) in which a single color impression was sensed by a color naming method, by using a texture pattern made by two different Munsell-hue elements. The results showed that the ΔH depended on the anchor test color, and that its extent was not restricted to a categorical color of the two elements' colors. These results suggest that a single color impression of a multi-colored texture pattern was not determined only by the categorical color perception of the elements.

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Color matching from memory

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ABSTRACT

Short-term color memory of two groups of university students, 20 with prior color coursework, and 20 with no color-related training, was evaluated in four hue categories: yellow, yellow-red, green, and purple. Munsell dimensions of hue, value, and chroma were used to select four target colors and nine distractor colors for each of the targets. Four of the distractor colors differed from the target in hue only, four were of the same hue as the target, but differed in both value and chroma, and one was identical to the target in both hue and value, but differed in chroma. The subject looked at the target color chip for 5 seconds, with the intent of remembering it. After removal of the target color, and an additional period of 5 seconds during which the subject focused on a white card, the subject was given a stack of ten randomly arranged color chips, including the target and the nine distractors, and asked to choose the target color. Of the four target colors, yellow was the most accurately remembered color, followed by purple, orange, and finally, green. Subjects in the two groups reported the use of similar cues in remembering the target colors.

1. INTRODUCTION

Color memory has been described as "successive color matching", a category of color matching in which time elapses between the presentation of a color stimulus and the attempt to match the remembered color (de Fez et al. 2001, Pérez-Carpinell et al. 1998).

Noting that certain colors have inherent differences that make them more difficult to remember than others, Collins (1931) conducted experiments in which subjects were asked to reproduce a previously seen color, and found that particular wavelengths of green and red were hard for the subjects to reproduce and also difficult to recognize again. This finding was confirmed by Hamwi and Landis (1955), who found that in addition to hue, ability to remember a color is also influenced by its lightness or darkness. Later, Nilsson and Nelson (1981) found that the most accurately remembered colors were violets, green-blues, and yellow-oranges. However, Jin and Shevell (1996) demonstrated that long and medium wavelengths were remembered more accurately than shorter wavelengths.

Pérez-Carpinell et al. (1998) found that women remember color more easily and more accurately than men. Among ten colors studied, orange was the easiest color to remember, whereas yellow, light green, blue and pink were the most difficult to remember overall. Comparing color memory by gender, male subjects most easily remembered orange, dark blue, green, and red, while women showed better memory for orange, red, chamois, and violet. Furthermore, light colors were remembered as being lighter than they actually were, while dark colors were incorrectly remembered as being darker (Pérez-Carpinell et al. 1998).

Time between stimulus and recall was also found to be a significant effect on memory, with the accuracy of color memory diminishing rapidly as the elapsed time increased between intervals of zero, 15 seconds, 5 minutes and 24 hours (Pérez-Carpinell et al. 1998). However,

Nilson and Nelson (1981) found no significant difference for delays between 0.1 and 24.3 seconds. Using longer delays of 15 minutes, 24 hours, and 64 hours, Hamwi and Landis (1955) also found no relationship between time delay and color memory.

Studies that addressed effects of subject's prior training or experience with color on their accuracy in color memory have shown contradictory results. Using 43 chips from the Farnsworth-Munsell color test, Burnham and Clark (1955) did not find prior color experience or training to be significant. However, earlier work (Collins 1931) with a questionably small sample of only six subjects had shown that trained subjects had more accurate color memory.

The primary purpose of our study was to examine the effect of prior color training or professional experience on short-term color memory. In effect, we examined differences between the ability of design majors (color-trained) and non-design majors (non-color-trained) to correctly retain selected colors in short-term memory. Another purpose was to examine incorrectly remembered colors to determine whether there is a consistent direction of hue, value, or chroma shift between the target and the remembered color. A third objective was to investigate whether subjects used word cues or visual cues in attempting to remember colors.

2. METHOD

Munsell dimensions (hue, value and chroma) were used to select colors for the study. Color chips in four hue categories (yellow, yellow-red, green and purple) were selected from the *Munsell book of color* (matte finish). Each set included a target color and nine distractor colors. The Munsell designations for the four target colors were 2.5Y 8/8, 7.5YR 7/8, 10G 6/6, and 5P 5/6. The Munsell locations of the distractor colors with respect to the target colors were the same for each of the four sets, and are listed in Table 1. All distractors were closely related to, but visibly different from the target color. Each color chip measured 17 × 20 mm and was mounted on a 2 × 2-inch white card.

Table 1. Target colors and distractors.

Target Color	Yellow 2.5Y8/8	Yellow-red 5YR7/8	Green 10G6/6	Purple 5PB5/6
Distractors	5Y8/8	5YR7/8	5BG5/6	2.5PB5/6
	10YR8/8	10YR7/8	2.5BG6/6	7.5P5/6
	7.5Y8/8	2.5Y7/8	7.5G6/6	10P5/6
	7.5YR8/8	2.5YR7/8	5G6/6	10PB5/6
	2.5Y8/6	7.5YR6/6	10G7/4	5P6/8
	2.5Y8/10	7.5YR8/6	10G7/8	5P6/4
	2.5Y7/6	7.5YR8/10	10G5/4	5P4/4
	2.5Y7/10	7.5YR6/10	10G5/8	5P4/8
	2.5Y8/12	7.5YR7/12	10G6/10	5P5/10

Subjects were forty female college students that were equally divided into two groups: design majors with prior training or professional experience with color, and non-design majors with no prior color training. Using the Farnsworth-Munsell 100 Hue Test, all were found to have normal color vision and at least average color discrimination ability.

The subject was handed the target color chip and asked to look at it with the intent of remembering it. After five seconds, the target specimen was removed. Then, after focusing on

an 8.5 × 11-inch standard white paper card for five seconds, the subject was handed a stack of ten color chips which included the target chip and the nine distractors, randomly arranged, and was asked to recall and choose the target color. Finally, after identifying what was thought to be the correct target color, the subject was asked what method was used in trying to remember the test color, i.e., whether the subject tried to remember the color by assigning it a verbal description or by using associations with mental images of objects having the same color.

3. RESULTS

The overall results are summarized in Table 2. Yellow was the most accurately remembered color, with 29 of the 40 subjects accurately selecting the target. Next was purple, then yellow-red, and finally, the least accurately identified color was green, correctly chosen by only four subjects. Considering design and non-design majors separately, yellow was the most accurately identified color and green was the least accurately identified color by both groups, but for the design majors, orange ranked second in number of correct matches, while purple was the second most accurately matched color for the non-design majors.

Table 2. Correct color identifications by subject groups.

Target Color	Design Majors	Non-Majors	Total
2.5Y8/8	15	14	29
7.5YR7/8	8	6	14
10G6/6	4	1	5
5PB5/6	6	10	16

For subjects who did not correctly identify the target color, various distractors were selected. For the target color yellow, the distractors selected by the design majors differed from the target only in hue. Similar results were found for the non-majors, except that one subject chose a distractor that differed from the target in value and chroma, but not in hue. For the yellow-red target, all except two chosen distractors differed from the target only in hue. One design major selected a distractor which differed from the target only in chroma, and one non-design major selected a target which differed in both value and chroma. For the green target, majority of the distractors for both groups differed from the target in hue. The exceptions among the design majors were one whose choice differed in value and chroma and one whose choice differed only in chroma. Among the non-design majors there were three exceptions whose selections differed from the target in both value and chroma. In the case of purple, the majority of the selected distractors also differed from the target in hue only. Exceptions were four students, two from each group, each of whom selected distractors that differed from the target in both value and chroma.

In response to the question of what cues were used to remember the color, most of the respondents stated that they used either words or visual associations with objects of the same color. Some of the subjects indicated that they used both types of cues. Design majors and non-majors were almost identical with respect to cue category primarily used, with both groups indicating greater use of visual cues. The maximum number of correct matches that were possible in the study was 160 (40 subjects × 4 colors). Of the 65 total correct matches that were made, the primarily used cues were visual in 41 cases, while word cues were primarily used in 24.

4. DISCUSSION

Confirming the findings of previous studies by Pérez-Carpinell et al. (1998), and Collins (1931), green was the least correctly remembered color for both groups. Contrary to the previous studies by Pérez-Carpinell et al. (1998), but confirming the findings of Collins (1931), yellow was the most correctly remembered color.

The learning (or practice) effect found by Collins (1931) and by Hamwi and Landis (1955), did not occur. On the contrary, most subjects correctly identified the first color presented and tended to lose accuracy in colors presented later. There was no strong difference between the design and non-design majors in overall ability to correctly retain colors in short-term memory. This observation confirms the findings of Burnham and Clark (1955), who concluded that immediate memory for a hue is not much affected by specific training in color.

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Color ratings for safety signs by young and elderly people

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ABSTRACT

When devising for safety colors, it is desirable to predict the physical and physiological effects to use. This paper reports on the results of experiments concerning how young and elderly people perceive the colors used for safety signs.

1. INTRODUCTION

Visual displays installed in and outside buildings include signals, signage, posters and advertising signs. It is advisable that these have a high level of visibility and conspicuity. Above all, colors to be used for the facilities and signage of the disaster prevention and emergency systems are stipulated as safety colors in the Japanese Industrial Standards. It is desirable if one can ascertain prior to color planning, what kind of psychological and biological effects these colors have on people. This paper reports on the results of experiments concerning how young and elderly people perceive the colors used for safety signs and their surroundings.

2. SUMMARY OF THE EXPERIMENTS

A questionnaire on color preferences and visibility experiments were conducted. The evaluation experiments using young people were carried out in a lecture room, the interior of which was finished in achromatic colors and the windows covered with lightproof curtains. White fluorescent lamps were used for the light source, while the average illuminance on the desks was approximately 600 lx. The indoor temperature was more or less constant during the experiments. The experimental subjects consisted of 217 students (105 males, 111 females and one unknown) with an average age of 19.6 (18 to 25). In the case of the elderly, the subjects consisted of 228 students (128 males and 100 females) of a senior citizens' college with an average age of 66 (58 to 80; 11 in their 50s), while similar indoor environmental conditions with those for the young subjects were applied.

The visual evaluation samples used in the experiments for the young people were 54-color charts as shown in Table 1; 32 colors with high to medium chroma saturation, seven safety colors, 11 commonly used interior finish colors and six achromatic colors. For the elderly, 50-color charts excluding the four achromatic colors were used.

Table 1. Color samples used for evaluation.

Type	Munsell Notation for each sample *Duplication
High chroma	5R 4/14, 5YR 7/14, 5Y 8/12, 5GY 7/10, 5G 5/8, 5BG 5/8, 5B 5/8, 5PB 4/12, 5P 4/12, 5RP 4/12, 5R 5/10, 5YR 5/10, 5Y 5/10, 5PB 5/10, 5P 5/10, 5RP 5/10
Medium chroma	5R 5/6, 5YR 5/6, 5Y 5/6, 5GY 5/6, 5G 5/6*, 5BG 5/6, 5B 5/6, 5PB 5/6, 5P 5/6, 5RP 5/6, 5R 5/8, 5YR 5/8, 5Y 5/8, 5PB 5/8, 5P 5/8, 5RP 5/8
Safety colors	2.5RP 4/10, 5R 4/12, 2.5Y 8/10, 2.5YR 6/14, 2.5PB 5/6, 5G 5/6*, N9.5
Interior finish colors	10YR 9/2, 10YR 8/2, 10YR 8/4, 10YR 7/2, 10YR 6/2, 10YR 6/6, 7.5YR 9/2, 7.5YR 8/2, 5Y 9/2, 2.5G 7/3, 5YR 6/2
Achromatic colors	N2.5, N3, N5, N6, N7

The quantity evaluation method was applied to assess contrast sensitivity. Based on the setting of the contrast sensitivity (difference) between the standard visual sample (N3.5) and its background (N7) with a rating of 100, the experimental subjects stated their perception of each visual sample for evaluation based on a value of zero or more. Two rectangular samples (visual distance: 30 cm and visual angle: 3.2° × 2.4°) were displayed in the center of background N7 with the standard sample on the right and the evaluation sample on the left.

3. RESULTS AND DISCUSSION

1) Color preference characteristics

In the case of the young subjects, 13 colors (ten hues plus white, gray and black) were evaluated based on five rankings. Figure 1 shows the evaluation results for white, blue, reddish-purple and yellow. Over 80% of both male and female subjects answered "Like" or "Slightly like" for white, blue and black, and approximately 40% of them answered "Dislike" or "Slightly dislike" for reddish-purple and purple. There is some gender difference regarding the perception of the yellow tone colors (yellow, yellowish-red and yellowish-green). Regarding the most preferred colors, the male subjects answered blue, white and black, while the females answered blue, red, yellow and white. Both male and female subjects answered that they dislike reddish-purple and purple the most, which more or less corresponds to the above evaluation of color preferences.

In the case of the elderly subjects, Figure 2 shows the color preference of the elderly. Regarding the male subjects, a little less than 80% answered "Like" or "Slightly like" for green and a little less than 60% for white, while over 60% answered "Dislike" or "Slightly dislike" for gray and over 50% for black. Regarding the female subjects, 90% answered "Like" or "Slightly like" for white and 70% for green, while a little less than 50% answered "Dislike" or "Slightly dislike" for gray.
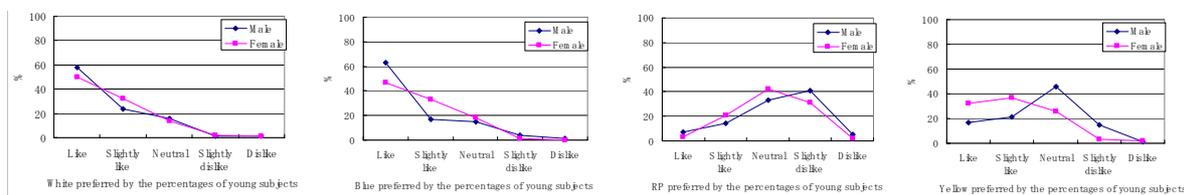
Figure 1. Colors preferred by young subjects.
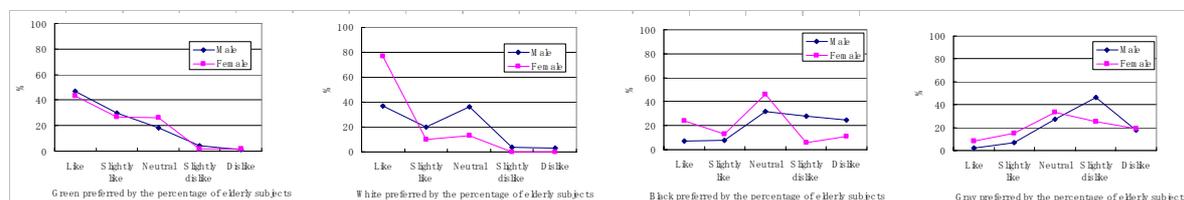
Figure 2. Colors preferred by young subjects.

2) Distribution of color rating

Contrast sensitivity rating and luminance contrast: Overall correlation was studied between achromatic and chromatic colors at the 50th percentile of the contrast sensitivity rating of the entire subjects (Figure 3). When the luminance contrast of the sample compared with the standard sample is positive, the larger the luminance contrast (absolute value), the greater the contrast sensitivity rating. Under the same luminance contrast, the rating of chromatic colors

is larger than that of achromatic colors. This result is the same as reported previously (Ohno, Satoh and Narasaki 1986, Ohno 1995).

In the case of the young subjects, Figure 4 shows the results of ratings at the 10th, 50th and 90th percentiles. The axis of ordinates represents the rating and the axis of abscissas represents the luminance contrast. The figure shows that the rating of each sample increased with chroma saturation of the visual sample, and chromatic colors show higher values compared with achromatic colors, under the same luminance contrast. These results were reconfirmed by the experiments using a large number of subjects this time. It was also found that rating for the preferred color is not necessarily associated with that of its perception, as the most preferred color blue showed a lower rating than the standard achromatic sample. The experiment also revealed that the female subjects generally showed a 20% higher visual sensitivity to color than the male subjects.

In the case of the elderly subjects, Figure 5 shows the results of ratings of the 10th, 50th and 90th percentiles. Under the same luminance contrast, the rating of each sample increased with chroma saturation of the sample, while chromatic colors show higher values compared with achromatic colors, just as shown in the case of the young subjects. The tendency was for the ratings at the 90th percentile to be lower than that of the young subjects, while slightly higher at the 10th percentiles.
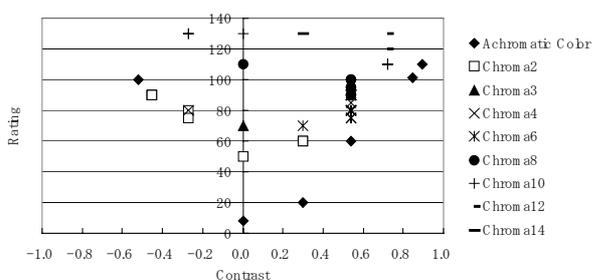
Figure 3. Contrasts and ratings on young and elderly subjects.
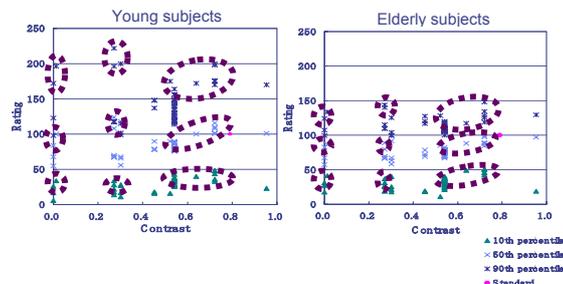
Fig. 4. Young subjects.   *Fig. 5. Elderly subjects.*

3) Safety colors (JIS 1972)

In the case of the young subjects, Figure 6 shows the ratings of the safety colors. At the 90th percentile, based on N9.5 (letters/background), the rating of 2.5RP 4/10 (radioactivity) was approximately twice that of the standard sample, 5R 4/12 (stop) 2.5 times higher, and 2.5Y 8/10 (caution) and 2.5YR 6/14 (danger) 2.8 times higher. Regarding the ratings at the 50th percentile, "radioactivity" was 1 to 1.1 times higher than the standard sample, "stop" 1.2 times higher, and "warning" and "danger" 1.3 times higher. These results proved that the safety colors are serving their role. However, although 2.5PB 5/6 (precaution) and 5G 5/6 (safety) at the 90th percentile was 1.5 times the standard, it was 0.9 times at the 50th percentile, which is lower than the standard value. As it is desirable that more than half of the experimental subjects give a higher rating for these colors than the standard visual sample, its improvement remains as a future task.

In the case of the elderly subjects, Figure 7 shows the ratings of the safety colors. The 50th percentile rating by the elderly was lower than the standard by nearly 20%, which raises the question as to whether the safety colors are serving their role. Colors designated for precaution, danger and warning especially showed low ratings.

4) Comparison between young and elderly people
4.1) Evaluation of the contrast sensitivity regarding safety colors

Comparison was made between young and elderly people concerning the ratings for safety colors. At the 90th percentile, it is clear that the young subjects in general showed a rating 1.6 to 2.6 times higher, compared with the elderly. At the 50th percentile, the young subjects showed a rating that was approximately 10% higher than the elderly. More notably, while the young subjects showed a rating 2.5 times higher than the standard, in 2.5RP 4/10 (radioactivity) based on N9.5 (letters/background), which also exceed the standard in 2.5Y 8/10 (warning) and 2.5YR 6/14 (danger), the elderly showed values for those colors that are lower than the standard. This suggests that re-consideration should be given to these colors, as they appear to be easy for young people to perceive, but not for the elderly.

4.2) Contrast sensitivity rating and luminance contrast

Figure 8 shows the correlation between the contrast sensitivity rating at the 50th percentile and the luminance contrast of each sample, for the young and elderly subjects. This shows that the distribution of the contrast sensitivity ratings is narrower in the case of the elderly compared with the young. This reveals that the said values evaluated by the elderly are less likely to be influenced by the changes of luminance contrast or colors.

4. CONCLUSIONS

1) The contrast sensitivity rating increases in proportion to the luminance contrast and chroma saturation. This result is the same as already reported.
2) Regarding perception of colors, the elderly's ratings are lower than those of the young subjects at the 90th and 50th percentiles, while there is no difference between them at the 10th percentile.
3) Regarding the perception of safety colors stipulated by JIS (1972), the young subjects' ratings are low for radioactivity, precaution and safety, while the elderly evaluated all safety colors as low despite their high luminance and chroma saturation.
4) Regarding the safety colors, further considerations should be given to the form of signs and relations with their surroundings, in addition to the colors themselves. As a revision of safety colors is currently being studied in Japan, the author hopes that these experiments can serve as part of the reference materials.
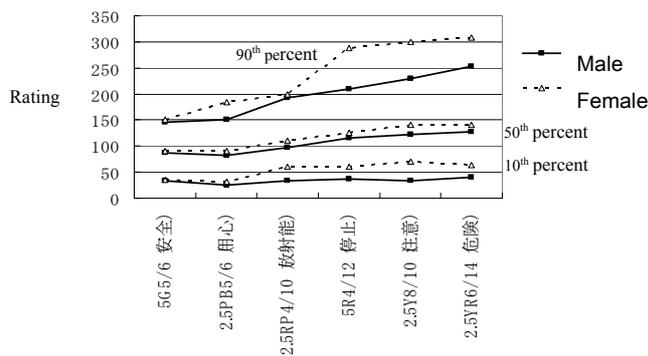
Figure 6. Ratings by young people.   *Figure 7. Ratings by elderly people.*
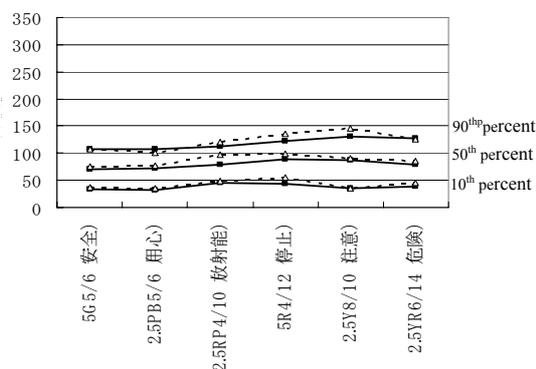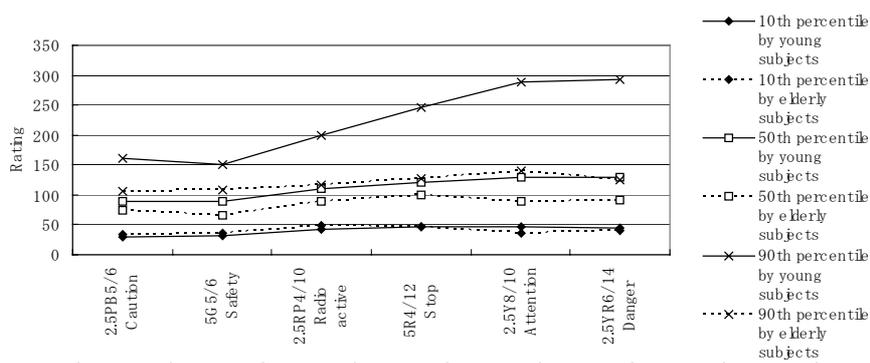
Figure 8. Comparison between young and elderly people on ratings of the safety colors.

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Colour emotions in larger and smaller scale

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ABSTRACT

It is well known that a colour's appearance can differ between a small colour chip and the same colour applied to a real room. The impression of the colour changes between these circumstances; e.g. on the chip it can be subdued, while it is perceived as striking in the room. In this paper, we compare the results of a colour chip study, colour emotion, to Hårleman's full-scale room study.

In the first study, textile chips were viewed against a grey background in a viewing cabinet. In the other study, two rooms were painted in 12 hues in two different nuances: NCS 1010 and NCS 1030. They correspond well to the hue areas and to two of the nuance categories used in the chip study. Semantic scaling was used in both studies. The two studies show a distinct difference between words associated to colours of the same nuance and colour category. A clear pattern could be seen. In the room, the colours were perceived as more distinct, stronger and they arouse much stronger emotions. Generally, a colour chip had to be much more colourful to give comparable associations.

1. INTRODUCTION

How does the context affect our associations towards colour? It is a well-known fact that the colour experience differs, depending on whether it is applied to a small surface or to a whole room. In this text, two studies will be compared. One is Maud Hårleman's investigation into the colour experience in painted rooms, lit by daylight in north- and south facing direction (Hårleman 2001, 2004). The other study is the Swedish part of the international project Colour Emotion Research and Application (Billger, Stahre and Konradsson 2002).

The aim is to describe differences and similarities in the way we perceive colours, on the basis of the context's significance and the size of the colour field. In this text, only the results from the north facing room in Hårleman's study will be compared with the colour samples of the colour emotion-study, due to the fact that this is the light best resembling neutral light.

2. METHODS

2.1 Hårleman's room-study

In her investigations, Hårleman has conducted studies in two full-scale rooms with similar colour schemes, observed in light from the north and south. Her question is whether the rooms get a different character through the differences in colour the light creates. Additionally six hues in two nuances were used for painting the rooms; 3 light pink, 3 pink, 2 light green and 3 green paints, and a yellow and a blue. 90 observers carried out a total of 118 studies.

Semantic differential scales, graded from one to six, have been used to describe the character of the rooms, complemented with oral interviews. The meanings of the different

significant variables on the differential scales have over the years been tested by many researchers (Kunishima and Yanase 1985, Küller 1980, 1991, Sivik and Taft 1992). It has been determined that they sort under different factors for different research fields, like colour in room-model, exterior-colour, single colours and colour combinations. Hogg et al. (1979) discovered five factors which concern colour in room-models. In Hårleman's room study, four of these have been used to sort the different variables of experience. These factors are: *temperature* (cold, warm); *spatial quality* (small, clear, open, dry, hard); *dynamism* (tranquil, lively) and *emotional tone* (gloomy, cheerful, nice, formal, sunny). In addition, two untested variables of experience have been added (surrounding and elevating). These sort under the factor *emotional tone*.

2.2 The colour emotion-study

During the spring of 2002, the Swedish part of the international colour emotion-study was carried out at Chalmers, which aimed to investigate how people from different countries and cultures associate towards colours. The study was led by Tetsuya Sato of the Kyoto Institute of Technology and Jim Nobbs of the University of Leeds. In all of the countries 114 colour chips, in 10-12 nuances of 10 hues, were used along with 6 achromatic samples. The colour samples were observed against a neutral grey background in a viewing cabinet with simulated (D65). In the Swedish part of the study 60 observers participated, with equal numbers of men and women.

A semantic 2-point method was used for the assessment, which meant that the observers chose which word in a word-pair corresponded most with the colour. The translation of the Japanese words was done in each country. In Sweden a translation was done based upon both Japanese and English. Twelve word-pairs were used in the study: Deep-Pale, Dynamic-Passive, Distinct-Vague, Gaudy-Plain, Heavy-Light, Light-Dark, Soft-Hard, Striking-Subdued, Strong-Weak, Transparent-Turbid, Vivid-Dull and Warm-Cold.

2.3 Comparison of the two studies

How can the different studies be compared? The colour emotion-study (CE) has more adjectives describing each colour, while the room study focuses more on the feelings and experiences of the room. Often we cannot compare the studies word for word, however we can translate the words to reasonably correlate with the other study and thus gain a picture of how the colours were perceived in the different situations. Also if we gather the descriptive adjectives from each study, we get a collection of impressions which together provide us with a clearer picture for comparison.

The two studies are based upon two different colour order systems. In the room-study the NCS-system was used and the CE-study used the system SCOTDIC PLUS 2000, which is based on Munsell's colour order system and adjusted to textile samples. To make the comparison between the two studies correct, we have visually translated the textile chips into the NCS-system (see Figure 1).
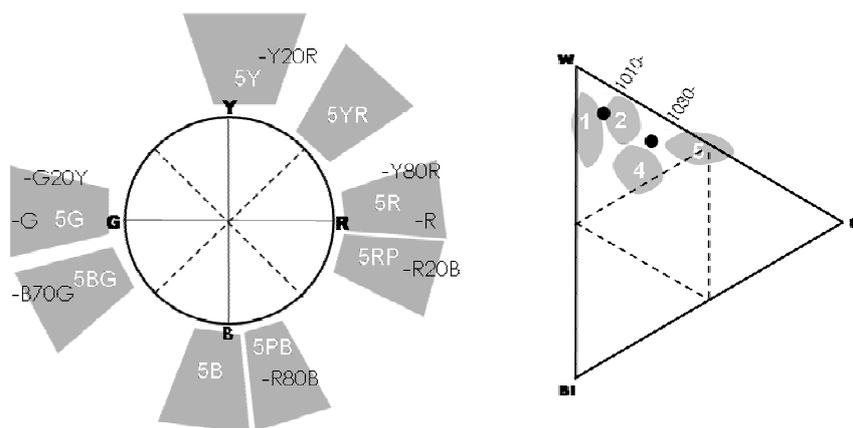
Figure 1. Left: The grey areas with white text are the hue areas in CE. The black text shows the hues of the room study. Right: Nuance areas in CE with white text. Black text and mark for the room study.

3. RESULTS

In Hårleman's room-study it was the *pink* and *green* colours that caused the strongest experiences. These experiences were distinctly different and associated to different aspects. The green rooms were experienced as open, tranquil and lacking cheerfulness, as well as more formal and hard. The light green rooms were experienced to be cooler and more open, while the green rooms were relatively warmer and more surrounding. The blue-green room however, was experienced to be the coldest. The pink rooms were perceived to be neither formal nor tranquil and gave a cheerful impression. They gave a surrounding and lively feel and were also the colours which the observers reacted strongest to in the study. All of the pink rooms were described as warm, except for the bluish pink, which was described as cold. The light pink and the pink rooms offered a similar experience, while the light green and the green rooms differed.

The differences between the pink colours in the room-study and the samples closest to them in the CE-study are striking. The light pink CE-samples are more colourful than the colours in the room-study, but were experienced as weak, subdued, fairly passive and calm. Half of the observers also described it as a cold colour. The pink hues correspond in the CE-study to three colour chips, of which one is somewhat greyer and the two others a lot more colourful. What is interesting is that the more colourful samples correspond a lot better to the room-study. They were perceived as dynamic, striking, vivid, strong, soft and gaudy. The same inherent colour[1] on a small textile sample was thus experienced as a weaker colour, which did not cause as strong reactions as the corresponding colours in the room-study. In the CE-study also more colourfulness in the samples was needed for the reddish colours to be experienced as warm. The lighter nuance 1010- was experienced as colder than the nuance 1030- in the room-study. This corresponds to that whitish colours were in general experienced as colder than the more colourful samples in the CE-study. Of the textile samples we here refer to, only the colourful pink was experienced as warm in the CE-study.

In the room-study both the light green and the green colours were considered tranquil, with the light green rooms more formal and tranquil than the green ones. The tendency towards less tranquillity with enhanced colourfulness agrees with the results of the CE-study. This effect however seems to demand a higher colourfulness in the green room than on the textile samples. Most observers thought that the textile samples equivalent to the paint in the room were striking and gaudy, and more than half thought they were vivid.

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[1] *Inherent colour* is defined as the colour property of the material that does not change due to viewing and lighting conditions. Here it is used for the NCS-code of the paints and the Munsell-code of the textile chips.

On the other hand the resemblances are significant between the light green rooms and the colour samples closest to them in the CE-study. The rooms were experienced as open, tranquil and enhancing the boring character of the test-room. This correspond to the CE-study, were the light green textile samples were described as passive, subdued, weak and calm.

In general, the pink rooms were experienced as soft while the green rooms were neither soft nor hard. In the colour emotion-study neither the pink nor the green colour chips were experienced as clearly hard or soft.

4. CONCLUSION

In the colour emotion-study, its grey frame and the viewing cabinet as well as the room surround the colour chip in general. The colours appear more subdued than in the room-study. In a room you are surrounded by colour, you are inside it. The colour reflections of the room enhance both the colour and the colour experience. The displacement of colour in the room-study makes them stronger in colourfulness and blackness, and will hence correspond to a different CE-sample. To compare the experience of a room-colour and a colour in the CE-study, the CE-sample must be from a significantly stronger nuance.

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Color-emotion associations:
Past experience and personal preference

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ABSTRACT

This study examined color-emotion associations and the reasons for emotional reactions given to colors. Ten fully saturated chromatic colors were chosen from the Munsell color system: red, yellow, green, blue, purple, yellow-red, green-yellow, blue-green, purple-blue, and red-purple. Apart from these ten hue groups, three achromatic colors (white, black and gray) were also used. The sample consisted of 98 volunteered college students at a public institution in the southeast region of the US. Results revealed that the principle hues comprised the highest number of positive emotional responses, followed by the intermediate hues and the achromatic colors. Color symbolism seems to be apparent in how individuals associate colors with things, objects or physical space. Red-purple, for instance, was associated with the color of red wine, plum, bridesmaid dress, or the color of a bedroom. Overall, a color-related emotion was highly dependent on personal preference and one's past experience with that particular color.

1. INTRODUCTION

Colors can relate to our emotions and feelings. For instance, the color blue is associated with comfort and security, orange is perceived as distressing and upsetting, yellow as cheerful, purple as dignified (Ballast 2002, Mahnke 1996). The color red has both positive and negative impressions such as active, strong, and passionate, but on the other hand aggressive, bloody, raging and intense. The color green has a retiring and relaxing effect. It too has both positive and negative impressions such as quietness, naturalness, and conversely tiredness and guilt (Davey 1998, Linton 1999).

In a study examining color-emotion associations, Boyatzis and Varghese (1994) found that light colors (e.g., yellow, blue) are associated with positive emotions (e.g., happy, strong) and dark colors (e.g., black, gray) with negative emotions (e.g., sad, angry). Hemphill (1996) also found that bright colors elicited mainly positive emotional associations, while dark colors elicited negative emotional associations, confirming the results obtained by Boyatzis and Varghese (1994). However, Saito (1996) found that the color black elicited both negative and positive responses among Japanese subjects, and that black was often a preferred color among young people.

Although the impact of color on our emotions has been examined considerably, many studies have failed to use color samples from a standardized system of color notation (Boyatzis and Varghese 1994, Hemphill 1996), while others elicited individuals' responses to verbal labels of color (e.g., "red", "blue") instead of using actual color stimuli. Furthermore, several studies have used color-emotion matching tasks; matching colors (e.g., red, blue) to a certain number of emotions (e.g., happiness, sadness), which results in limited assessments of reactions to colors.

The purpose of this study was to examine college students' color-emotion associations, referencing color samples from the standardized Munsell color system and to investigate the reasons for students' emotional reactions to each color.

2. METHOD

Ninety-eight volunteered college students (44 men and 54 women) participated in the study. They were asked to indicate their emotional responses to five principle hues (i.e., red, yellow, green, blue, purple), five intermediate hues (i.e., yellow-red, green-yellow, blue-green, purple-blue, and red-purple), and three achromatic colors (white, gray, and black) and the reasons for their choices. The Munsell notations are shown in Table 1.

Table 1. Munsell notations.

Color	Munsell
Red	5R 5/14
Yellow	7.5Y 9/10
Green	2.5G 5/10
Blue	10B 6/10
Purple	5P 5/10
Yellow-red	5YR 7/12
Green-yellow	2.5GY 8/10
Blue-green	5BG 7/8
Purple-blue	7.5PB 5/12
Red-purple	10RP 4/12
White	N/9
Gray	N/5
Black	N/1

The color samples were prepared by using Freehand 10.0 software, in which Munsell color notations were available in that computer program. Each color sample (10 cm × 12 cm) was displayed in the middle of the computer screen one at a time. Order of presentation of the color samples was randomized across participants. Students were allowed to state only one emotional response for each color. Each experimental session lasted for about ten minutes.

3. RESULTS

Based on the results obtained from the students' responses, the color green attained the highest number of positive emotions (95.9%), including the feelings of relaxation, followed by happiness, comfort, peace, and hope. Green was associated with nature and trees, and thus creating feelings of comfort and soothing emotions. The color yellow was generally seen to be energetic and elicited positive emotions (93.9%) including happiness and excitement because it was associated with the sun and summer time. The next highest number of positive response was given for the color blue (79.6%), followed by red and purple (64.3% each). Blue was associated with the ocean or the sky and thus inducing relaxing and calming effect. The color red was associated not only with love and romance, but with evil and blood. One respondent said that the color red reminded her of Valentine's Day and the shape of heart. Another said that the color reminds her of red lingerie. The positive aspects of purple are tended to be

mainly associated with children and laughing, while reasons given for negative responses to purple consistently showed that purple was not a favorite color.

Among the intermediate hues, the blue-green elicited the highest number of positive responses (81.6%), followed by red-purple (76.5%), yellow-red (75.4%), and purple-blue (65.3%). On the contrary, the color green-yellow elicited the highest number (71.4%) of negative emotional responses because it elicited the feelings of sickness and disgust.

For the achromatic colors, white attained a large number of positive responses (61.2%), compared with only 19.4% and 7.1% positive responses for the colors black and gray, respectively. White was associated with the feelings of innocence, peace, and hope because it reminded some respondents of bride, snow, dove, and cotton. Reasons given for negative emotional responses to white showed that white elicited the feelings of loneliness and boredom. The color black was also evoked negative emotions such as depression, fear, and anger because it was associated with mourning and tragic events. The positive aspects of black were richness, wealth, and power. It also reminded some respondents of tuxedos and formal gowns. Reasons given for negative emotional responses to gray showed that the color gray tends to refer to bad weather and brings out the feelings of sadness, depression, and boredom.

4. DISCUSSION

Color symbolism can be apparent in how individuals associate colors with things, objects or physical space. For instance, in the present study, the color yellow-red was associated with the color of autumn or Halloween. One respondent said that yellow-red made her happy because it reminded her of school buses and her childhood. Furthermore, the color blue-green was associated not only with the ocean and the sky, but also reminded some respondents of cool mints and toothpaste. Some associated black with "power," and said it reminded them of nice sport cars. Black made some respondents feel sophisticated and reminded them of "fashion and clothing". Yet, another respondent said the color black made him sad and reminded him of "funerals where people wear black". Therefore, a color-related emotion is highly dependent on personal preference and one's past experience with that particular color. A replication of this study at different institutions could give us a more comprehensive understanding of the issues raised here. Cross-site studies could be conducted to identify similar or different patterns in students' emotional associations to colors.

Moreover, color conventions differ from one society to another. A well-known example is with the two achromatic colors; black and white. Death and mourning are associated with the color black in Western traditions, whereas in China the color of death is white. In the present study, the color black was associated not only with royalty, power, and wealth, but with death, mourning, and tragic events. Cross-cultural research could shed light on these issues by determining how cultural differences vary in color-emotion associations.

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Quantitative analysis of Thai sensation on colour combination

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ABSTRACT

Colour sensations of Thai observers were examined for 253 colour pairs generated from a set of 23 single colours selected from the PCCS colour system. The colour samples included five colour hues (red, yellow, green, blue and purple) varied in four different tones (vivid, dull, light and dark) and three achromatic samples (white, medium grey and black). Observers identified colour sensation induced by each colour pair using fourteen opponent-word pairs: Dark-Light, Hard-Soft, Cool-Warm, Turbid-Transparent, Pale-Deep, Vague-Distinct, Light-Heavy, Sombre-Vivid, Weak-Strong, Passive-Dynamic, Plain-Gaudy, Subdued-Striking, Disharmony-Harmony and Dislike-like, whereby the magnitude of each sensation scale was divided into 7 categories. Thirty-four observers took part in the experiment. The experimental raw data were analysed statistically to obtain visual scores for all of fourteen sensation scales. No simple correlation was found between colour sensations of two-colour combinations and differences in lightness, chroma and hue between the two colours in a given pair. The results of correlation coefficients showed that there were some relationships between two colour-sensation scales.

1. INTRODUCTION

As colour is one of the critical factors influencing customers' satisfactory, an understanding of colour sensations is thus important in product design. Colour sensations for single colours have long been studied (Osgood, Suci and Tannenbaum 1957, Wright and Rainwater 1962, Hogg 1969, Sato et al. 2000, Ou et al. 2004a). However, in daily life, we often see various colours in combinations, rather than single colours. Furthermore, the sensation induced by a single colour is generally different from that by a combination of colours. Culture, background knowledge and personal preference also yield differences in colour sensations. Sato et al. (2000) developed a number of colour-sensation formulae for single colours based on the experimental data obtained from Japanese observers. Ou et al. (2004a, 2004b) studied colour sensations of British and Chinese observers. This study aimed to investigate the sensation of Thai observers for two-colour combinations.

2. METHODOLOGY

A psychophysical experiment was carried out to investigate colour sensations for two-colour combinations. Colour samples used in the study were selected from the PCCS colour system. The colour samples included five colour hues (red, yellow, green, blue and purple) varied in

four different tones (vivid, dull, light and dark) and three achromatic samples (white, medium grey and black). There were thus 23 single colour patches used in the experiment. Each of the sample patches was 3 × 3 inches in size. A set of 253 colour pairs was generated from these single colour patches. Colorimetric values of the colour samples were measured in terms of lightness (L*), chroma (C^*_{ab}) and hue (h_{ab}) using a Gretag Macbeth Color Eye 7000 spectrophotmeter. Colour difference (ΔE^*_{ab}), lightness difference (ΔL^*), chroma difference (ΔC^*_{ab}) and hue difference (ΔH^*_{ab}) were calculated for each colour pair.

The experiment was conducted in a darkened room where each of the colour pairs was presented in a standard light cabinet under D65 light sources. Thirty-four Thai observers (17 males and 17 females) ranging in age from 20-27 took part in the experiment. Colour-sensation scales were investigated using fourteen opponent-word pairs: Dark-Light, Hard-Soft, Cool-Warm, Turbid-Transparent, Pale-Deep, Vague-Distinct, Light-Heavy, Sombre-Vivid, Weak-Strong, Passive-Dynamic, Plain-Gaudy, Subdued-Striking, Disharmony-Harmony and Dislike-like. Observers were asked to identify the magnitude of each colour-sensation scale which was divided into 7 levels, i.e. −3, −2, −1, 0, +1, +2, +3 (Figure 1).

+ 3													
Light	Soft	Warm	Transparent	Deep	Distinct	Heavy	Vivid	Strong	Dynamic	Gaudy	Striking	Harmony	Like
⇕	⇕	⇕	⇕	⇕	⇕	⇕	⇕	⇕	⇕	⇕	⇕	⇕	⇕
Dark	Hard	Cool	Turbid	Pale	Vague	Light	Sombre	Weak	Passive	Plain	Subdued	Dis-Harmony	Dis-Like
− 3													

Figure 1. Colour-sensation scales.

The experimental raw data accumulated from 34 observers were calculated to obtained visual scores representing the colour sensation in terms of a percentage ranging from +100% to −100%, as given in equation 1:

$$VS\% = \frac{a(-3)+b(-2)+c(-1)+d(0)+e(+1)+f(+2)+g(+3)}{3(a+b+c+d+e+f+g)} \times 100 \qquad (1)$$

where *a, b, c, d, e, f* and *g* are the number of observers choosing the score of −3, −2, −1, 0, 1, 2 and 3, respectively.

3. RESULTS AND DISCUSSIONS

The visual scores for each of the colour-sensation scales were plotted against the values of colour difference, lightness difference, chroma difference, and hue difference between two colours of a given pair. The results showed no simple correlation between the visual scores and the colorimetric differences in a given pair, as the plots were scattered with dots with hardly any trend. However, colour difference seemed to affect colour-sensation scales of Vague-Distinct, Sombre-Vivid, Passive-Dynamic, Plain-Gaudy, Subdued-Striking, and Disharmony-Harmony. When colour differences were large, the magnitude of colour sensations trended to increase towards the Distinct, Vivid, Dynamic, Gaudy, Striking, and Disharmony direction. Examples of these trends are shown in Figure 2.
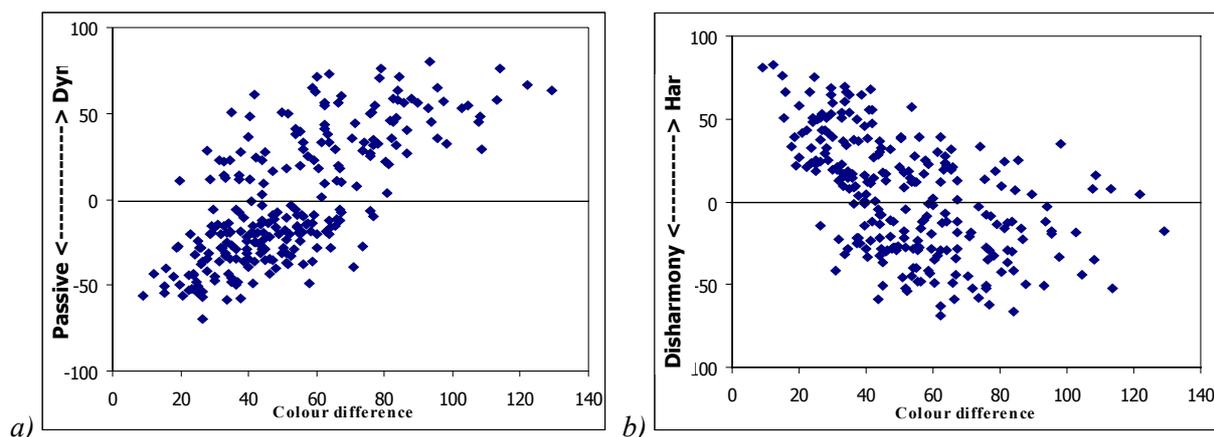
Figure 2. Relationships between colour difference and a) Passive-Dynamic scale and b) Disharmony-Harmony scale.

The factor analysis was carried out in this study to reduce a large data set from a group of interrelated variables into a smaller set of not correlated ones, so as to reveal underlying factors of the fourteen colour-sensation scales for Thai observers. The extraction method of principle component analysis and an orthogonal rotation were used. Three factors accounting for 88.57% of total variance were extracted from the visual scores. The results are summarised in Table 1. Component 1 consisted of Plain-Gaudy, Subdued-Striking, Passive-Dynamic, Vague-Distinct, Sombre-Vivid and Cool-Warm. Component 2 contained Light-Heavy, Turbid-Transparent, Dark-Light, Hard-Soft, Pale-Deep and Weak-Strong, and Component 3 was composed of Dislike-Like and Disharmony-Harmony. These results agreed well with those found in the study by Ou et al. (2004b).

Table 1. Factor matrix of two-colour sensations for Thai observers.

Colour sensations	Component 1	Component 2	Component 3
Plain-Gaudy	0.95	0.07	−0.11
Subdued-Striking	0.92	−0.10	0.20
Passive-Dynamic	0.90	0.26	−0.14
Vague-Distinct	0.84	0.29	0.29
Sombre-Vivid	0.79	0.59	0.16
Cool-Warm	0.63	0.27	−0.39
Light-Heavy	0.25	−0.92	0.18
Turbid-Transparent	0.32	0.91	0.00
Dark-Light	0.47	0.84	−0.05
Hard-Soft	−0.44	0.84	0.04
Pale-Deep	0.47	−0.79	0.29
Weak-Strong	0.40	−0.79	0.42
Dislike-Like	−0.22	0.49	0.79
Disharmony-Harmony	−0.47	0.26	0.73

Relationships between two of colour-sensation scales were evaluated. In the present study, the correlation coefficient was used to determine whether two ranges of data move together, that is, whether large values of one set are associated with large values of the other (positive correlation), whether small values of one set are associated with large values of the other

(negative correlation), or whether values in both sets are unrelated (correlation near zero). The correlation coefficients greater than 0.8 were found for Dark-Light and Turbid-Transparent (0.92), Passive-Dynamic and Plain-Gaudy (0.91), Pale-Deep and Light-Heavy (0.88), Pale-Deep and Weak-Strong (0.88), Vague-Distinct and Sombre-Vivid (0.86), Light-Heavy and Weak-Strong (0.86), Dark-Light and Sombre-Vivid (0.84), Plain-Gaudy and Subdued-Striking (0.83) and Vague-Distinct and Subdued-Striking (0.82). The correlation coefficients less than −0.8 were found for Hard-Soft and Light-Heavy (−0.85) and Hard-Soft and Pale-Deep (−0.84).

4. CONCLUSIONS

Colour sensations induced by two-colour combinations were studied for Thai observers. The preliminary results showed no simple correlation between the colour-sensation scales investigated and the differences in colorimetric values (lightness, chroma and hue) between the two colours in a given pair. Three underlying colour-sensation factors were extracted by means of the factor analysis, which agreed well with the earlier study (Ou et al. 2004b). Some relationships were found between two colour-sensation scales. An establishment of relationships between the sensations of single colours and colour pairs is still under going. Colour-sensation formulae for predicting the sensations induced by colour pairs will be presented in the near future.

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Looking for an invariant under daylight changes with L, M, S-type sensors

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ABSTRACT

We have studied the application of an illuminant-invariant parameter for color-vision mechanisms which allow us to transform a color image, taken in L-, M-, S-cone signals, into a gray-scale image which does not change when the illuminant does. First, we have tested the possibilities to define an invariant at a pixel used in previous results in this field with other sensors (Finlayson and Hordley 2001). In spite of a good correlation between cone-signals for different daylight illuminants, the definition of the invariant cannot be applied for a variety of objects. In fact, when we transform a color image into a gray-scale image for different phases of daylight, the image histograms do not superpose and then object recognition is impossible. Second, we have tried to improve the invariant in two ways. Due to the fact that the invariant works better for monochromatic sensors, we have employed spectral-sharpening techniques (Finlayson, Drew and Funt 1994) to linearly transform the spectral sensitivities of L, M and S into narrower ones. Also, we have tried to define the invariant based on second-site color signals instead of receptoral signals With these two strategies we obtained better results than with previous and a higher degree of color constancy.

1. INTRODUCTION

As far as color vision is concerned, one of the most interesting properties of the human visual system is what is known as color constancy, which is when the color of objects remains unchanged under specific observation conditions even if the light changes. The appearance of the color is maintained although the color measured colorimetrically changes. This does not occur for all changes of illuminant but does seem to hold good in natural daylight conditions such as may be found in natural landscapes. Some of the theories which try to explain color constancy have been applied to artificial vision to obtain devices for the recognition of images of objects regardless of changing light conditions. Some of the methods put forward for obtaining color constancy in artificial color systems could also be tested for human color vision and the aim of our work is to continue with this line of research. We have taken a recently proposed algorithm which predicts the color constancy of images (Marchant and Onyango 2000, Finlayson and Hordley 2001), and tested it by using the cones of the human color-vision system as sensors. The main characteristic of this algorithm is that it defines the observed or recorded scene pixel by pixel and thus does not require the global information about the scene, as was the case with previous algorithms. For this method to give an accurate reading of color constancy the sensors have to be monochromatic, that is to say with a spectral sensitivity of only one wavelength, and the illuminants must be Planckian. Various authors have shown the possibilities of this method when the conditions are not fulfilled (Marchant and Onyango 2001, 2002, Romero et al. 2004), producing good results in daylight conditions with Gaussian sensors (Romero et al. 2004). Finlayson and Hordley (2001) commented about the possibility of improving the application of the method if the sensors

used had wide spectral sensitivity and were subject to spectral-sharpening (Finlayson, Drew and Funt 1994), thereby concentrating the spectral information within a narrower wavelength interval.

We have analyzed the pixel-by-pixel method of color constancy applied to objects and images recorded in natural light conditions with varying meteorological factors, using the L, M and S cones as sensors. We repeated the calculations after applying the spectral-sharpening technique to the sensors. Finally, we analyzed the method by substituting the responses of the cones (first stage in color-vision models) for the responses of the second stage (opposing mechanisms: red-green, yellow-blue) because of the shared characteristics shown by the sensitivity of the sharpened L, M and S sensors and the opposing mechanisms.

The experimental method is based on the definition of an invariable parameter thus:

$$F_{12} = y_1 / y_2^{A_{12}} \tag{1}$$

where

$$y_1 = C_1 / C_n \quad \text{and} \quad y_2 = C_2 / C_n \tag{2}$$

$C_i = g \int s_i(\lambda)\rho(\lambda)E(\lambda)$ being the response of the spectral-sensitivity sensor $s_i(\lambda)$ corresponding to the spectral radiant generated by a reflecting object $\rho(\lambda)$ illuminated by the spectral power distribution (SPD) $E(\lambda)$. The term g covers all the components of the gain factor and the factors linked to the geometry of the illumination. We took cone L as sensor 1, cone S as sensor 2 and cone M as sensor n.

To make an experimental determination we used a graphic method (Finlayson and Hordley 2001), with the group of objects and illuminants being represented by the log of y_2 *versus* the log of y_1. If the invariable is valid for a group of sensors, this representation will generate for each object when illuminated with different illuminants dots which will fall upon a straight line, the slope of which, $1/A_{12}$, must be the same for all the objects involved. We chose as objects the 24 samples of the ColorChecker and 64 daylight SPDs corresponding to measurements made on days with different atmospheric conditions and different times of day, including noon and twilight. We took the sensitivity of the L, M and S cones to be in accordance with the fundamental responses proposed by Smith and Pokorny (1975).

2. RESULTS AND DISCUSSION

The results of the graphic representation are shown in Figure 1. If the invariable parameter is correct the slopes of all the straight lines should be the same, which as we can see is not the case. This is confirmed by the values of the average slope (−4.91) with its standard deviation (1.24) and the mean regression coefficient (0.88) with its standard deviation (0.04). In the light of these results we are not able to affirm that this method is effective for establishing color constancy using the human visual system.

As mentioned above, we applied the spectral-sharpening technique to the spectral sensitivity of the cones. The new sensitivities show negative terms recalling those of the opposing mechanisms of the second stage of color vision, although it does not coincide exactly. After applying the calculation of the invariant with the sharpened sensors we obtained the results shown in Figure 2. There is no significant improvement, due to the behavior of the invariant for certain objects. Therefore we are unable to conclude that the technique of spectral sharpening improves the application of the invariable, unlike the results obtained for artificial sensors, such as a CCD camera (Romero et al. 2004).
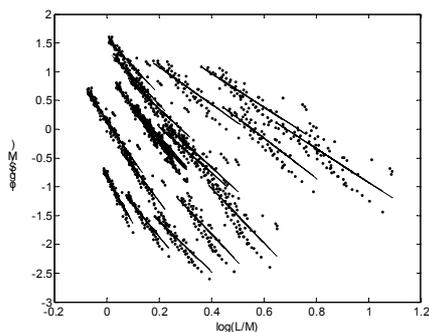
Figure 1. Log (S/M) versus the log (L/M) for the different objects and daylight SPDs.
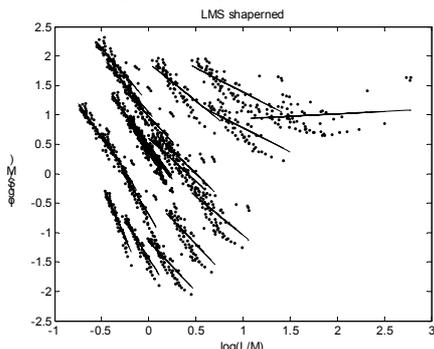
Figure 2. Log (S/M) versus the log (L/M) for the different objects and daylight SPD, when cone sensitivities have been previously sharpened.
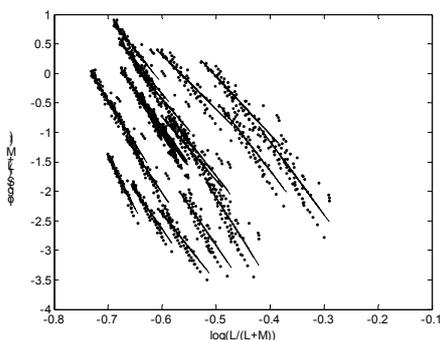
Figure 3. Log S/(L+M) versus the log L/(L+M) for the different objects and daylight SPDs.

Based on the above-mentioned considerations regarding second-stage opposing mechanisms, we calculated the invariable parameter once again, but this time with $y_1 =$ L/L+M and $y_2 =$ S/L+M, i.e. the responses of the red-green and yellow-blue mechanisms. The results are shown in Figure 3. We can see that now there is a definite improvement compared to the results obtained for L, M and S in Figure 1.The difference between the slopes is reduced, the maximum difference being 5,5º. Although the standard deviation of the slopes is greater, the value compared to the mean value is less and there is also an improvement in the mean regression coefficient factor of the straight lines. Thus, we believe that a computational model for color vision based upon the second-stage color-vision mechanisms improves the calculation of the invariant and allows us to explain to a greater extent, although not completely, color constancy *versus* changes in illumination produced by changes in daylight conditions.

Finally we applied the three invariables calculated to a natural scene to see whether this method with these sensors might be applied to the recognition of objects. We used an image of a scene supplied by Nascimento, Ferreira and Foster (2002) and applied the calculation of the invariable, pixel by pixel for six daylight SPDs with color temperatures: 3757, 4425,

5555, 9091, 12449 and 32753 K. The scene was flowers upon a background of leaves and branches. Bimodal distributions obtained are not superimposed for any of the different illuminants, which would impede recognition of the objects (a flower in front of a background of leaves) invariant to changes in light conditions. We repeated the calculations for the two other groups of sensors used and calculated the intersection of the histogram corresponding to one daylight with the rest of those studied according to the index suggested by Finlayson, Schiele and Crowley (1998). The results show a slight improvement for the sharpened sensors and second-stage mechanisms compared to the L, M, and S sensors.

ACKNOWLEDGMENTS

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Metamerism in the visual system

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ABSTRACT

For the colour industry, metamerism is an unpopular word since it implies different mixes of the colours of the spectrum which can be seen to be the same only under certain conditions of light**.** However, can this assessment be extended to the visual system? Or could metamerism be the system's mechanism to *balance* the stimuli it receives? The results obtained bring to mind an assertion made by MacAdam to the effect that the law of additivity when applied to luminance is not applied to measurements of brightness. If in this case additivity cannot be considered, we are undoubtedly up against a non-linearity for which the system has to compensate. In this paper we shall seek to answer these questions

1. INTRODUCTION

Back in 1972, in a study on colour equalization through the use of a combination of filters while controlling both brightness and colour, Jennifer Birch (1973) noticed that "some subjects found it possible to match the test colour with more than one combination, while others could not". "When individual results are plotted on the CIE diagram two distinct patterns are obtained. Firstly the matches may appear to occur along a line similar to the isochromatic lines described by Pitt (1935), or secondly they may appear to be grouped within a MacAdam ellipse". These two observations, which were substantiated in one of our earlier papers, did not prevent each equalization being considered correct for the observers who took part in the experiments.

The question that we would specifically like to formulate today is whether the metameric equalizations of dichoptic chromatic mixes are more dependent on brightness than on hue. In other words, which of these two variables is furthest from those inherent in the colour to be equaled. Adding the problem of dichoptic vision the mix of three or four primaries, as proposed by this study, has as its sole objective to place the visual system in different circumstances that might allow an analysis of variability and strategy of balance in greater depth.

2. METHOD

Experiments were carried out with a Wright-type visual colorimeter to which was added a new channel in order to reproduce the dichoptic situation. The two sets of primaries chosen were 650, 530 and 460 nm, and 650, 565, 513 and 460 nm. There were nine colours to be reproduced: 650, 600, 570, 550, 530, 520, 515, 500 and 450 nm. The retinal illumination was kept constant at an average of 40 trolands. Four observers of normal colour vision aged between 35 and 40 took part in the experiments. For each experimental situation and observer (four altogether) three estimations per stimulus were made, and these values were then averaged out.

3. RESULTS

Figure 1 shows a summary of the different colour matching functions (CMFs) obtained. The insert indicates the experimental condition corresponding to each CMF. In this Figure, the CMF peak positions reveal that the greatest variation or "adjustment" of the functions to experimental variations is as a result of luminance. The peak of lowest luminosity corresponds to the classic situation of monocular vision with three primaries; the maximum corresponds to an equal situation but using four primaries. The difference of luminosity between both is of 120 trolands, while the variation in wavelength is only around 25 nm.

It should be noted that in our study, the channel that led the sum of three primaries generated a more degraded signal than the channel that transmitted only one primary, creating in consequence an imbalance that the system had to solve and which is critical within the range of mean wavelengths. As observed by Guild (1931), Wright (1928-1929) and Stiles (1955), there is greater variability in the spectral region between 470 and 500 nm region where two photopigments are active (Smith and Pokorny 1975, Wright 1928-1929) observes that in this region the different colour matchings exceed the error in psychophysical measuring and could reflect receptor differences. For Smith and Pokorny (1975) this variability could be due to a variation in differential density of the screening pigment, while for Lee et al. (1990) to the selective participation of each receptor. Nevertheless, these observations do not invalidate the assertion that the initial absorption of light by photoreceptors is linear, due to the fact that the photoreceptor signal is proportional to quantal absorption over a substantial range above the absolute threshold for vision (Schnapf et al. 1990). Afterwards, the non-linearity would be produced post-receptorially due to the combination of photoreceptors.

In the Figure it can be seen that except in the dichoptic case in which primary red is isolated (+), the peak of functions is maintained around 560 nm, a situation which clearly corresponds to photopic vision, with which we worked in this study. Nevertheless, the most important feature is variation of the five functions obtained as regards luminance, particularly when bearing in mind that in all cases the observers reproduced the same nine wavelengths. This variation indicates strong metamerism and an automatic balance of luminosity.
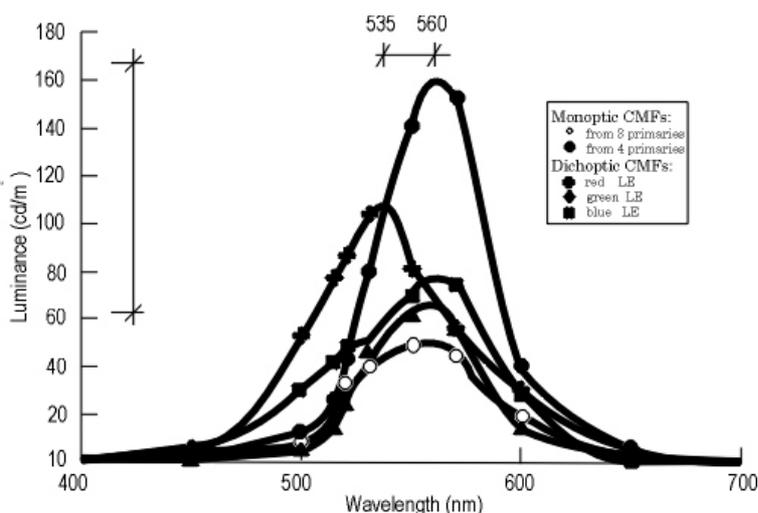
Figure 1. Five luminosity functions obtained in different experimental conditions as indicated in the chart. Note the stability of the peaks as regards wavelength (550-560 nm) as opposed to the variation of luminance (45-158 cd/m^2).

Figure 2 compares luminosity incident in the right eye with the left, reflecting the balance mentioned, which Levelt (1965) interpreted by proposing the following equation:

$$C = W_I E_I + W_D E_D,$$

in which C is binocular brightness, E is the sum of luminance that reaches each eye and W_I and W_D are coefficients of weight or gain. This non-lineal equation considers that the sum of W_I and W_D must be constant and equal to the unit and which is where in the relationship between these two values the visual system finds its balance. The Levelt model is reflected in the full 45-degree lines, and our data in the points and broken lines intermediate to them. We believe that the most important feature of the Figure is that, at low levels of brightness the channel that carries just one primary is dominant (W3), but at high values —as is logical— the channel that adds more than one primary predominates.
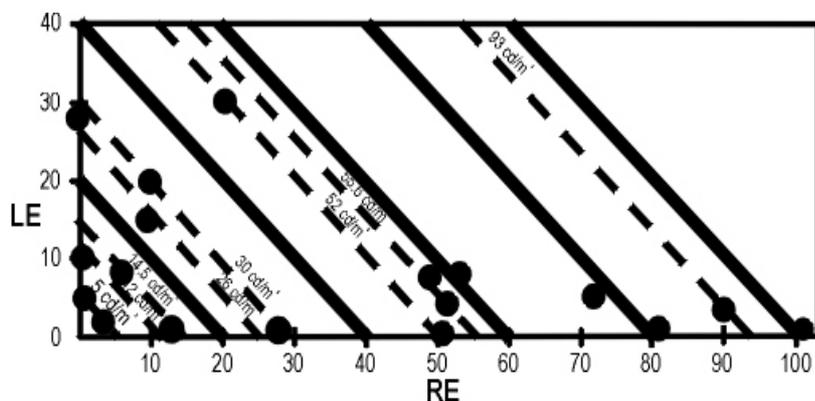
Figure 2. Comparison of incidental light in the right eye (RE) compared to the left eye (LE). The Figure proves the balance established between both eyes, a balance that in our case is adjusted to the Levelt model (1965). The 45-degree lines, dotted or not, indicate zones of equal brightness.

This balance is also reinforced by the data in Figure 3 illustrating the difference in brightness between the monoptic and dichoptic measurements, indicating that the sum of the functions, respecting their signal, produces a strict symmetry of mirror reflection, which indicates the presence of an undisputed balance.

On this point, we analysed in a previous paper (Mattiello, Biondini and Salinas 1999) the gain function for the different primaries used, obtaining functions that correlated the luminance of the monoptic (abscissa) and dichoptic (ordered) mixtures. The slopes of these functions were equal to 1.03, 1.38 and 1.45 for red, green and blue primaries respectively. These values coincided with data supplied by Simmons and Kingdom (1998) in a study carried out on binocular summation. These functions again indicated the increase of luminosity required by the green-blue zone when dichoptic vision is used.

It should be remembered that, by definition, luminance is an additive quantity. MacAdam (1970) proved that the law of additivity applied to luminance is not applied to measurements of brightness. Visually brightness is not additive, so CMFs should not be considered as significant functions when computing tristimuli values R, G and B since they are not lineal.

This observation is generally not taken into account in the majority of practical cases, nor is the strong metamerism observed when matching identical wavelengths with different primaries and experimental conditions. Nevertheless, the maximum sensitivity peaks obtained throughout the study are not far from the normal patterns indicated in the bibliography (Thornton 1999) despite the strong metamerism observed. This does not occur with luminance that presented a notable variability, as we have already remarked. In conclusion we can say that: the summation of brightness is given by the sum of the luminosity from each eye, affected by convenient functions of weight. This produces a non-lineal result but does not alter light balance. So, the changes recorded within well-defined limits indicate two important facts: 1) a strong *stability* of the visual system when dealing with colour, making colour a basic and preattentive sensation (Treisman 1985) that allows monoptic and/or dichoptic functions to be solved with equal success even from different sets of primaries, and 2) a *plasticity* of the system which allows it to keep itself in balance based especially on the adjustment of retinal illumination. Highlighting these facts has been the principal aim of this paper.
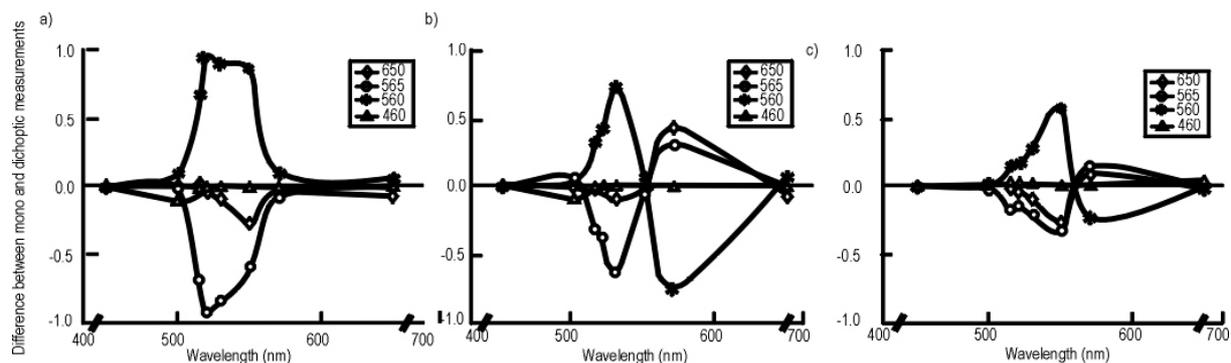
Figure 3. Difference between monoptic and dichoptic measurements obtained with four primaries. In a) the 650 nm primary was isolated, in b) the 560 nm, and in c) the 460 nm. Note that by adding up the differences and respecting the sign perfect symmetry is seen.

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Readability of chromatic documents

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ABSTRACT

It is a well-known fact that the readability of any document depends on the contrast between text and background. Although the case of achromatic documents has been the subject of frequent in-depth studies, the subject has once again become an issue due to the large-scale appearance of web pages in color. Obviously, it is impossible to estimate the readability of chromatic documents by using only the three visual factors of achromatic documents: letter size and style, contrast, and luminance of adaptation. For example, in the case of documents whose luminance contrast is 0.0, those with no color difference between letters and background cannot be read, but those with enough color contrast difference can be read in certain cases. This study will deal with the subject by first establishing a measure of reference between achromatic and chromatic contrast, before defining the equivalent luminance contrast of an achromatic document whose readability is equal to that of the chromatic document, and where the background luminance and letter size are equal. It then analyzes the contribution of color in the absence of differences in luminance. Finally, it proves the inhibitory effect of high luminosity backgrounds on texts of medium or low luminance and the effect of color on luminance.

1. INTRODUCTION

In this study, the influence of color on readability is reported. The data is acquired by determining the readability of chromatic documents with methods and criteria already used in the analysis of achromatic documents (Blackwell and Blackwell 1980). The information obtained is also analyzed in the same experimental sequence to facilitate the comparison of data. Experiments were undertaken in order to understand their influence on readability: 1) the alphabets, of size C14, Arial Bold, Cosmos Extra Bold and Impact designated in the Figures as families I, II and III respectively; 2) color participation, when luminance remains variable, or when luminance is kept constant and purity varies; 3) the detection of a border between letters and background as an alternative way of quantifying contrast; 4) high luminance backgrounds which allow for an increase in the effect of contrast, thus making texts more readable. The influence of letter size to be known is not analyzed, nor is the influence of the level of illumination since it is a subject which is more closely related to luminotechnics and/or the visual state of the observer.

Besides setting out guidelines for the design of chromatic web pages, this paper must be clarified in order to specify or compose a uniform color space which represents the influence of color on readability. However, it should be remembered here that the relations of contrast are more conclusive for the visual system than color variations in defining shapes by the detection of their borders. On the contrary, color has a significant function in graphic messages, due to its power in attracting attention or its symbolic value, which frequently says more than the message itself.

2. EXPERIMENTAL METHOD

A personal computer was used during the experiments, in order to reproduce the situation in which graphic designers generally work. The HSB color ordering system of PHOTO SHOP Version 7 was used. It was agreed that colorimetric measurements would not be made since designers in general do not have distance measuring systems. As a consequence, the measurements presented here are a result of the values assigned by the HSB system and must therefore be considered as being only referential and not physical.

Two psychophysical methods were used to measure the contrast between background and letter: that of magnitude estimation – with a fixed variable numeric scale of 0 to100, and that of readability estimation using a scale of four categories: "unreadable", "barely readable", "readable" and "highly readable". Five texts were considered during the experiments, a variety that allowed learning processes to be excluded. The sentences were of the same length, degree of comprehension and letter size. Luminance contrast of letters and background was defined as a quotient obtained by dividing the luminance difference by the lowest luminance. Letter size subtended a visual angle of 1 degree. Texts were presented on a PC screen in a dark environment. The screen was subdivided into three equal and horizontal zones: in the central one the texts to be estimated were placed together with their respective backgrounds; when the texts were achromatic the higher and lower zones presented a medium gray equal to 50%, and to 5% when they were chromatic.

Ten university students of an average age of 20 years took part in the experiments using the readability estimation method. They all had 10/10 visual acuity and correct color vision. They had no previous experience in this kind of study. Another four trained observers estimated the distinction in borders by applying the method of magnitude estimation, the results of which appear in Figures 2 to 5 as dotted line.
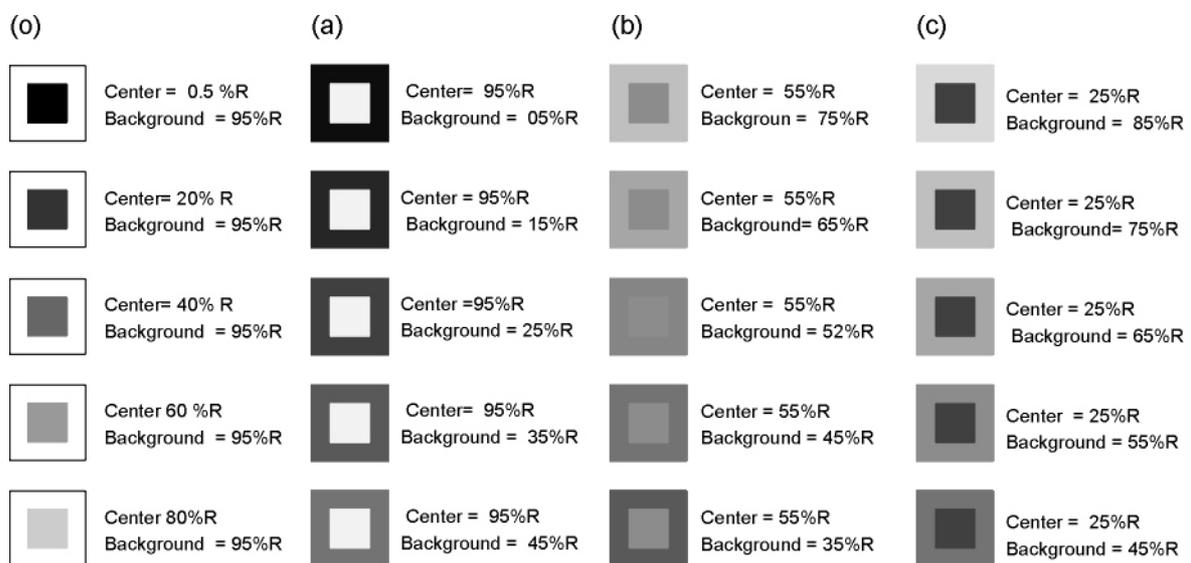
Figura 1

Figure 1.

The form set of samples combinations of the achromatic and chromatic documents were set up as follows: Figure 2: three alphabet families (I, II and III), gray letters variable in luminance and a white background; Figure 3: family II, gray letters and backgrounds varying in luminance between a situation with a high distinction of borders to another with minimal distinction; Figure 4: family II, equal relation of luminances as in Figure 3 but using three

semi-opponent color (purple-yellow, red-green and blue-orange). Figure1 summarizes the achromatic situations of Figures 2 and 3.

3. RESULTS

Figure 2 sums up the results obtained using both the experimental methods chosen and the three selected alphabets, and applying to the letters different values of grays printed on a white background. The estimation of readability is represented with a full line and the detection of borders with a dotted line. The influence of the type of letter on readability can be observed along with the results obtained with border detection method. These results are measure of contrast and bring to mind those obtained by Blackwell and Blackwell.
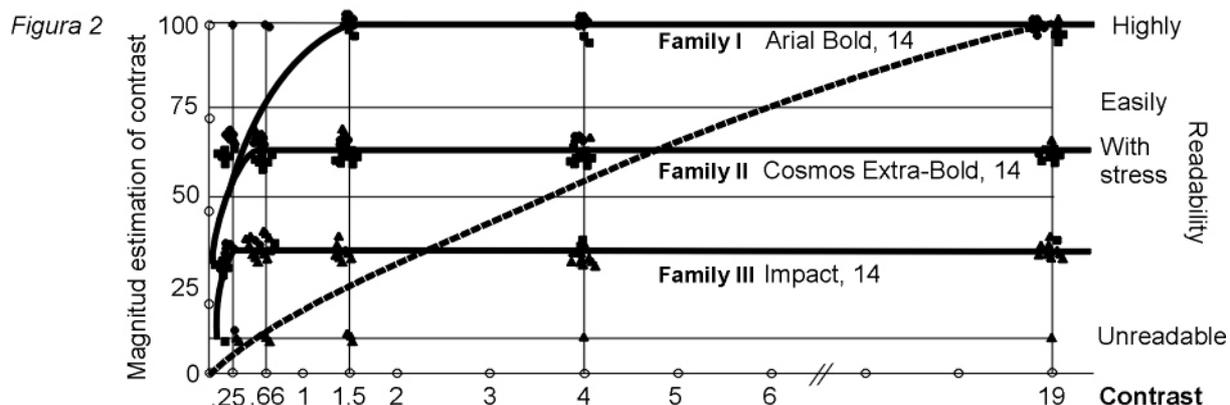
Figure 2.

Comparing Figure 3 —where only family II is used— with the data obtained with the same alphabet in Figure 2, it can be observed that it is the contrast relationship which marks the differences in the case of Figure 3. Also, although it could be said that each border detection accompanies each one of the readability cases analyzed, the results are completely different. In Figures 2 and 3, the space between these two types of measurements would appear to indicate the zone in which, for a certain contrast condition (see Figure 1), these two magnitudes may vary. Thus, according to the circumstances, it is readability that exceeds border detection while in others detection exceeds readability. It is important to mention that when the observers estimated detection they centered their vision on the simple elements of the message, such as the letters *l* or *i*. When they estimated readability their attention was focused on understanding the written message. Only in the first case can we refer to a simple estimation of contrast, but in the second cognitive factors are brought into play.

Before completing the analysis, we should mention the inhibitory effect generated on letters by light backgrounds (Ratliff and Hartline 1974). This can be appreciated when comparing the experimental situations detailed in Figure 1 with the results in Figures 2 and 3. It should be remembered that the inhibition produced by light backgrounds means that gray letters are perceived as being darker; in consequence, their readability increases. It should also be noted that the constant readability presented by family II in Figure 2, starting with a contrast equal to 0.66%, is reached in Figure 3 only from a contrast of 1.1%, an effect which is due to the different luminance relationship between letter-background. For example, the application of condition (b) in Figure 1 depresses readability to "unreadable" values and condition (c) —which in some cases presents a lighter background than the letter— reaches the condition of "highly readable" at a contrast of 2.4%, a value never reached by this family

in the conditions shown in Figure 2. Going on to analyze the data from Figure 4, we should like to point out that the stimuli used presented a relation of luminance contrast equal to those in Figure 3, but including color both in the background and in the letters. These new results seem to show differences which can only be attributed to color. It should be noted in the Figure that situation (a) is "highly readable", beginning with a contrast of 4%. Condition (c) reaches equal value in a more abrupt way than in Figure 3, while condition (b) remains in a "readable" situation.
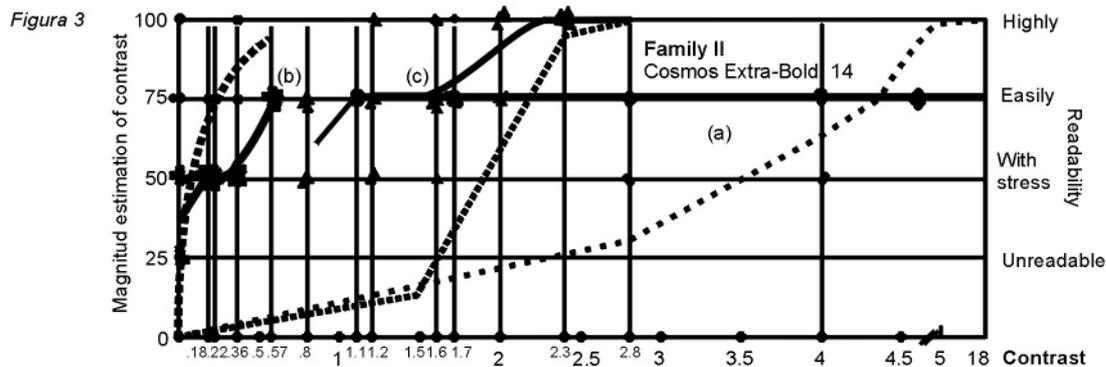
Figure 3.

Summing up, based on the data obtained in this and other experiments it could be said that the contribution of color to contrast would seem to be only from 15 to 20%. This contribution is related with another effect (Helmholtz-Kohlrausch) which Helmholtz noted when comparing two direct and simultaneous luminances of different colors. Later on Kohlrausch (1942) studied this effect experimentally and considered it to be of importance in heterochromatic measurement, like the effects summarized in Figure 4. Finally, the dotted line in this Figure shows the results obtained with color, but with the complete absence of luminic contrast and samples of a blue background and yellow-orange letters. During the experiments it was observed that the contrast of purity alone is not enough to make the texts "readable" and that certain chromatic situations can produce a "vibration" of color, which is counter-productive for good visual performance. This discomfort is similar to that produced by dazzling, a phenomenon which occurs when using an insufficiently shaded and incorrectly placed light source.
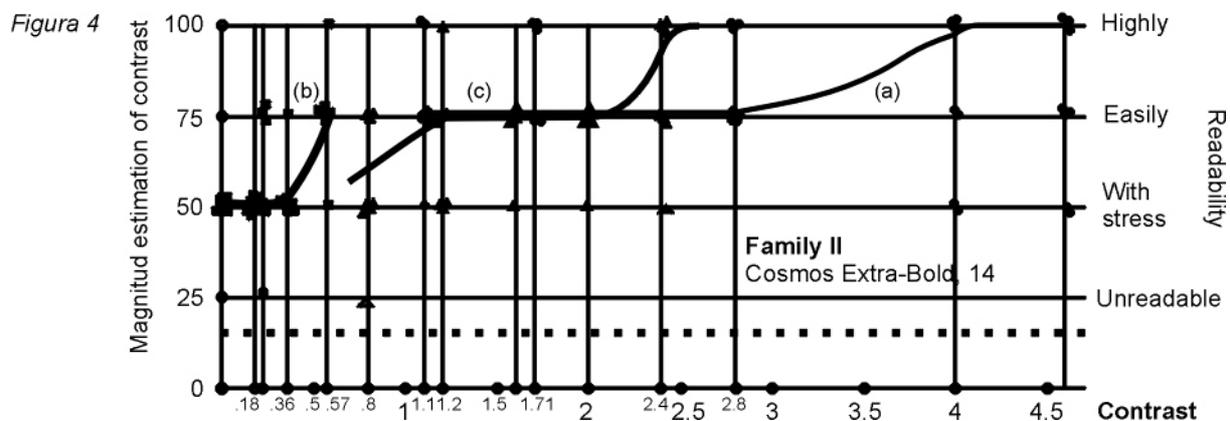
Figure 4.

In conclusion, although readability depends on contrast, it is a different estimation that involves more than a simple estimation of darkness or light. In this aspect, color contributes other properties, for example, its attraction on a text, which by arousing the attention begins cognitive processes which overcome certain visual difficulties. Therefore, although it is advisable to work with color and contrast together in graphic design, it is important to bear in mind the situations analyzed here.

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Binocular stochastic models for suprathreshold chromatic changes at isoluminance

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ABSTRACT

In the present work, we studied the structure of the binocular color mechanisms using simple visual reaction times (VRT) at equiluminance conditions. Uniform circular random step-wise pulses were presented on a color monitor at a 1.5-deg field size. Their chromaticity were selected along an L&M-constant cone axis and an S-constant cone axis to produce red, green, yellow or blue suprathreshold changes. The heterochromatic flicker photometry method was used to obtain an equiluminance level of 15 cd/m^2. Simple visual-reaction times for manual responses were registered on fovea under monocular and binocular observational conditions using the standard procedure. Two human observers with normal color vision took part in the experiment. To examine the rate at which responses were produced at each instant following stimulus presentation (events per millisecond), the hazard functions were calculated. Comparing binocular and monocular hazard functions, the patterns found cannot take into account by stochastic VRT models. The results found suggest that binocular color vision could be viewed as a distributed more than a point-combination process. Our results also suggest that the dynamics of parvo- and konio-cellular pathways should be incorporated in these models to take into account the binocular hazard functions at isoluminance.

1. INTRODUCTION

The perception of color plays an important role in the analysis of visual scenes (Gegenfurtner and Kiper 2003). The existence of binocular color interactions for both striate and extrastriate areas support the idea that color cells are widely distributed in the cortex (Anzai et al. 1999, Lennie 1998). However, cognitive modelers have been assumed that monocular inputs are combined in a unique step as a point process (e.g., Hughes and Townsend 1998, Westendorf and Blake 1988). In the study of the precise role of the basic binocular mechanisms that mediate chromaticity interactions, modern mental chronometry have been used to investigate their elementary visual organization throughout transient- and sustain-type systems (e.g., Jiménez et al. 2002, Luce 1986, Nissen and Pokorny 1977, Ueno 1992). In the present study, we measured VRTs at isoluminance conditions to test if binocular color vision can be modeled as a point process at the large scale of temporal integration.

2. METHODS

To produce visual stimuli with specific CIE-1931 chromatic and luminance coordinates, a computer connected to the CRT color monitor was used. The chromaticity and luminance of stimuli were controlled by periodic calibrations using a calibration method with a SpectraScan PR-704 PhotoResearch spectroradiometer. The experimental stimuli were

circular 1.5° patches of uniform color on a dark background and were observed in fovea with the natural pupil under three observational conditions: right and left monocular (a black patch occluded the opposite eye in each case, respectively), as well as binocular vision. Chromaticity variations were generated at isoluminance along an L&M- and an S-cone axis according to the Boynton's two-stage color-vision model (Boynton 1986). An achromatic reference stimulus of 15 cd/m^2 with chromaticity coordinates equal to those of the equal-energy illuminant ($x = 0.333$, $y = 0.333$) was chosen to produce suprathreshold variations. Visual-reaction-time data (VRT) were taken independently for each block of experimental conditions (red-green and yellow-blue at isoluminance). For each observer and for each observational condition, the heterochromatic flicker photometry was used previously at 12.3 Hz to match the luminance of each stimulus with the reference stimulus used in the experiments. Then, VRTs were measured following the standard procedure in order to ensure that only pure hue signals were detected by the observer (e.g., Jiménez et al. 2002, Nissen and Pokorny 1977). The computer clock was programmed to provide 1 ms timing. A chin rest was used for head stabilization.

At the beginning of each experimental session, observational conditions (binocular vision, right eye or left eye) were randomly varied and fixed for the duration of that session. Afterwards, the subject was allowed 3 min to adapt to darkness and 3 additional min to adapt to the achromatic reference stimulus. At this point, a tone followed by a 7-sec pause signaled the start of a trial. After a random delay (3-7 sec, uniform sampling distribution) to avoid anticipation, the reference stimulus was changed to the test stimulus with the change synchronized with the beginning of the video refresh cycle. The test stimulus that replaced the reference remained on until the subject responded by pressing the button on the mouse connected to the microcomputer to indicate that a stimulus change had been perceived. Immediately after a response, the test stimulus was replaced by the reference stimulus. Observers did not know which stimulus was the next in the sequence, and therefore their task consisted only of responding as soon as possible to an equiluminance variation. False alarms bellow 110 ms were excluded according with the standard procedure and misses were established at 1500 ms. Two human observers with normal color vision took part in the experiments.

For determining the rate at which responses were produced at each instant following stimulus presentation, the *hazard* functions *h(t)* were calculated for both binocular and monocular observational conditions using the standard procedure (Luce 1986). This function is defined (in events per millisecond) as $h(t) = f(t)/1 - F(t)$, where $f(t)$ and $F(t)$ indicate the density and cumulative probability functions, respectively, offer the noteworthy possibility of gathering more information at long processing times, i.e., in the right tail of the distributions (Luce 1986), taking into account the sustained and transient properties of the different color transmission pathways as a whole (Ueno 1992). Therefore, the hazard functions were compared for each observational condition (both binocular and monocular) in each experimental condition at isoluminance.

3. EXPERIMENTAL RESULTS

For both observers, the overall monocular and binocular hazard functions for the red-green and yellow-blue color axis at isoluminance were calculated in each case. The results indicated that both monocular and binocular hazard functions present similar patterns except at low and high processing times, where both observers showed high variability, with an identical binocular completion rate (events per millisecond), but in most cases lower than the monocular case, presenting higher values only within specific time intervals. As an example,

Figure 1 represents the results found for the red-green, (only observer JM) and yellow-blue signals (only observer JR). These differences persisted when hazard functions were analyzed for each experimental case for both observers.
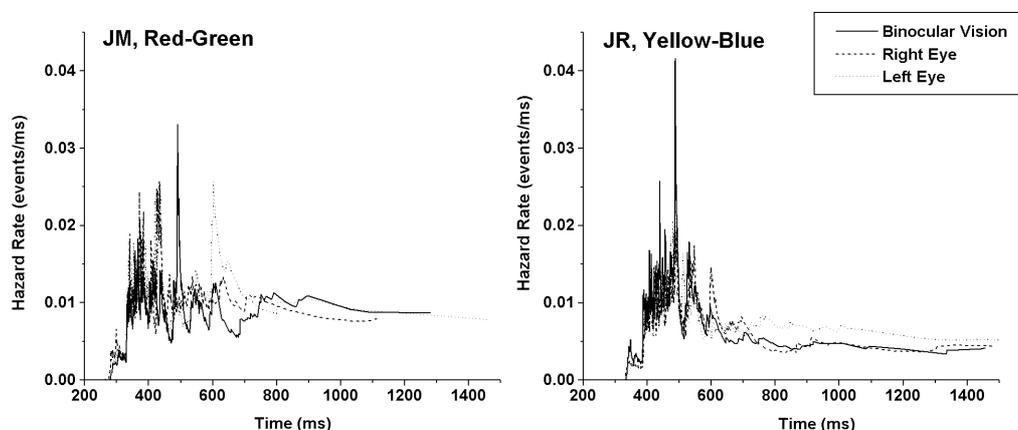
Figure 1. Monocular and binocular overall hazard functions for red-green and yellow-blue chromatic changes at isoluminance. Level of reference: 15 cd/m². Observers: JM and JR.

4. BINOCULAR VRT MODELS

Binocular-vision models for simple reaction time admit the existence of parallel channels up to a certain level to carry color information from photoreceptors to the cortex. However, although the information is conveyed in parallel, the visual-motor process immerse in a VRT task is carried out in serial stages (Luce 1986). This implies that VRT can be divided at least into two random variables: *VRT = D+R*, where *D* and *R* represent the decision and residual latencies, respectively, the former includes the transduction, the parallel transmission and the decision threshold stages whereas the latter will associate with non-visual process such as the motor response (Luce 1986). Therefore, binocular combination rules are usually proposed in *D* in a unique step (a point-process) until a criterion response is reached (co-activation models) or in terms of logical *OR* and *AND* gates (e.g., Hughes and Townsend 1998, Westendorf and Blake 1988). The time-homogeneous Poisson model assumes a neural counting process using the superposition principle as the binocular-combination rule. Thus, both monocular and binocular-decision density function can be modeled by a Gamma function, in the latter case, with the sum of their corresponding monocular-rate parameters (Luce 1986, Colonius 1990). However, only monotone increasing hazard functions can be derived (Luce 1986). On the other hand, Smith (1995) have been developed a VRT model in terms of a diffusion process, taking into account the transient and sustained characteristic presented by the human visual system. Thus, binocular vision can be treated similar to the monocular system but with multiple converging channels at the decision level. To combine them, an addition-like or Minkowski-type metric could be established (Smith 1995). However, binocular hazard functions are predicted equal to, strictly higher or strictly lower than the monocular ones and not presenting different alternatives in the time axis as Figure 1 revealed. Similar predictions could be made under a Poisson time-inhomogeneous model assuming that the integrated event rate define the threshold response for each observational condition. Finally, the parallel gains model predicts that the number of grains available rise in

binocular vision so, the net effect will raise the hazard rate translating them to the left in the time domain (Miller and Ulrich 2003).

5. CONCLUSIONS

The patterns found for each chromaticity signal at isoluminance showed different alternatives in the hazard functions for both observational conditions in different regions of the time axis. This imposes strong restrictions in binocular VRT models where a point-combination process is assumed.

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Investigation of simulated texture effect on perceived color differences

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ABSTRACT

Currently the International Commission on Illumination (CIE) recommends the study of the influence of texture on color-difference evaluation (Witt 1995). For textile samples the CIE has recommended the use of $k_L = 2$, $k_C = 1$, $k_H = 1$ in most recent color-difference formulas: CIE94 and CIEDE2000. Although this recommendation has been associated with texture, its origin is not well understood and additional research has been claimed. We have compiled visual data on the effect of simulated textures on suprathreshold color-tolerances using CRT sample pairs, and we analyzed separately the lightness, chroma and hue tolerances for the 5 CIE centers (Robertson 1978). Our texture is made up of randomly distributed dots, with different sizes, percentages of covered surface, and color attributes. Overall, 7706 suprathreshold visual tolerances have been obtained by 5 observers having non-defective color vision. In comparison with homogeneous color pairs, the textured ones showed about twice the lightness tolerances for the strongest textures. In addition, greater chroma and hue tolerances were also found for textured samples. Our data imply that, although the effect of texture on color differences might be relevant, it is not possible to provide a simple set of parametric factors for all potential textures available in industrial applications.

1. INTRODUCTION

Homogeneous samples are a useful simplification for most color studies. However, in many industrial applications the surface structure of the samples (texture) is outstanding and its effect on the perceived color differences appears to be relevant (Montag and Berns 2000, Han, Cui and Luo 2003, Xin, Lam and Luo 2003). Among the most influential parametric factors affecting color-difference evaluation, the CIE has recommended the study of texture (Witt 1995). More specifically, for textile samples the CIE has recommended the use of parametric coefficients $k_L = 2$, $k_C = 1$, $k_H = 1$ in the CIE94 (CIE 1995) and CIEDE2000 (CIE 2001) color-difference formulas, although the cause of this recommendation is not well known. Note that the previous recommendation assumes that for textile textures lightness tolerances are duplicated, while chroma and hue tolerances remain identical to the ones found for homogeneous color samples.

Our objective is to contribute to the study of the interactions between color and texture, particularly the influence of simulated textures on visually perceived color differences. We have used CRT samples pairs, with simulated textures constituted by randomly distributed dots on a homogeneous color sample. Simulated textures have been defined by three different parameters (size, percentage of covered surface, and color-modified attribute), which are systematically modified in our experiment. We have obtained the lightness, chroma and hue tolerances for the

5 CIE centers recommended in 1978 (Robertson 1978), considering both homogeneous and textured samples.

2. MATERIALS AND METHOD

2.1 Experimental device

We have used a calibrated Samsung SyncMaster 900p CRT color monitor, connected to a graphics card NVIDIA RIVA TNT2 Model 64 Pro 32 MB in a compatible-IBM PC, for the presentation of the samples.

For the management of our experiment, specific software developed by us has been used to display a test like the one shown in Figure 1. Two color pairs, each one subtending 6.2º from the observer's position, were compared. The right color pair (anchor pair) had a fixed color-difference of 1.6 CIELAB units. At each observation the observer could modify only one of the CIELAB parameters (L^*, C^*_{ab}, h_{ab}) in the left pair (test pair) in order to obtain just a greater color difference than the one shown by the anchor pair. Thus, we find separate color tolerances for each one of the three color attributes. The positions (up-down) of the color samples in the anchor and test pairs changed at random for different observations. Also the color attribute modified in the test pair changed at random during the experimental sessions. The anchor and test pairs are positioned on a neutral gray background with the following chromaticity coordinates: $x_{10} = 0.284$, $y_{10} = 0.303$, $Y_{10} = 24.78$ cd/m2, equivalent to $L^*_{10} = 50.96$. A white surround ($x_{10} = 0.284$, $y_{10} = 0.304$, $Y_{10} = 126.90$ cd/m2) subtending 1º has been used as reference white for transformation to CIELAB.
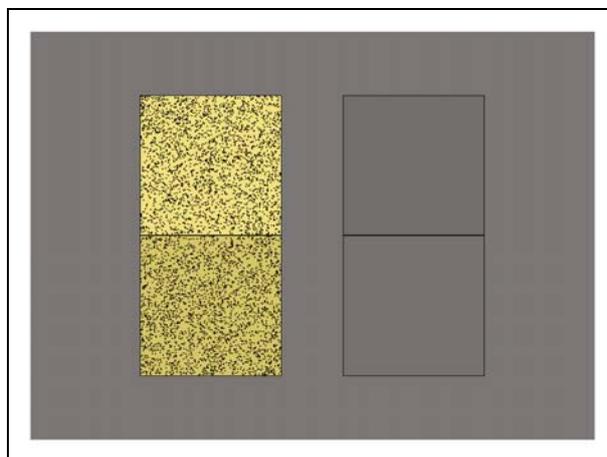
Figure 1. Example of visual test used in our experiment.

A panel of 5 experienced observers (3 females and 2 males) with normal color vision assessed each color pair in a darkened room, after 2 minutes of adaptation to darkness. In addition, between two successive observations the observer was adapted to the background and surround for 2 minutes. For each of the 5 centers, color tolerances were determined for homogeneous and 33 different textured pairs. Overall, 7706 suprathreshold visual tolerances were established.

2.2 Textures

Among the main objectives of this work it was to achieve a systematic change of well-defined textures. Thus, we have studied samples with simulated textures made up of dots randomly distributed on a homogeneous color. The next three variables of the texture were considered: size of the dots, color-difference between homogeneous color and dots, and percentage of surface covered by the dots. Specifically we have used dots with size 1 and 4 pixels. The color of the dots was of 5 different types: dots with lightness 10 CIELAB units more (type B) or less (type C) than the homogeneous samples, dots with chroma 15 CIELAB units more (type D) or less (type E) than the homogeneous samples, and black dots (type F). Type F was an "absolute" texture, while the others types (B, C, D, E) were "relative" textures. Texture type A was assigned to homogeneous color samples (without any texture). The percentage of surface covered by the dots in the samples was 5%, 20%, and 50%; and also 80% only in the case of the absolute textures. The three variables considered in the texture have been systematically modified and combined, providing 33 different textures for each CIE centre.

3. RESULTS AND DISCUSSION

The average difference between our 5 observers, calculated in terms of the PF/3 value (Guan and Luo 1999) was 42.3, with an average intra-observer variability of 18.9 PF/3 units. All the observers followed analogous trends for the different types of textures. The statistical analysis showed no interaction between the variable observer and the remaining variables considered by us. Thus, henceforth, we have used the average of our 5 observers.

In addition, for the 5 centers the results also showed approximately the same trends. The stronger the textures were, the higher the tolerances were. The two sizes of the dots in the texture gave results without statistically significant differences. No statistically significant differences were found, either, between homogeneous samples and the case of 5% of the samples covered with dots. For all observers and centers, supra-threshold visual tolerances increased with the remaining percentages of covered surface.

Figure 2 shows average tolerances for the five observers and five CIE centers against different types of textures previously defined.
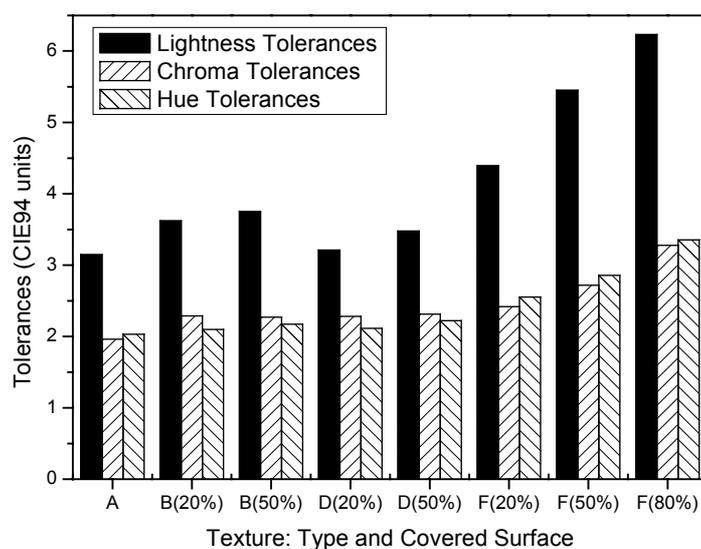
Figure 2. Average tolerances for different simulated textures (see text).

The influence over the tolerances proved higher for the absolute texture than for the relative ones. The relative textures exerted greater influence over their corresponding tolerances (that is, random dots with lightness changes increased mainly lightness tolerances). In all cases, textures reduced perceived color differences in a pair (i.e. increased tolerances).

The influence of the texture is higher on lightness tolerances than on chroma or hue tolerances. According to previous reports (Montag and Berns 2000), the lightness suprathreshold tolerances changed about 200% in the case of absolute texture with 80% of surface covered. For absolute texture and 80% covered surface, the chroma and hue tolerances also increased although more moderately (about 160%).

4. CONCLUSION

It is noteworthy that the influence of our simulated textures on chroma and hue tolerances is not negligible (i.e. k_C and k_H parametric factors might be greater than 1.0). We feel that although the effect of texture on color differences might be relevant, it is not possible to provide a simple set of parametric factors for all potential textures available in industrial applications, and each case must be studied independently.

ACKNOWLEDGMENTS

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Effect of luminance on color discrimination ellipses: Analysis and prediction of data

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ABSTRACT

The CIE and others have called for studies of the effects of luminance (*L*) on chromaticity discrimination. Four experimental data sets are analyzed here to quantify three such effects of *L*: on axis dimensions (*a* and *b*), *a/b* ratios, and ellipse areas. Ellipses for aperture, surface, and simulated surface colors in CIE 1931 and 1964 *x,y* diagrams are shown to reduce axis dimensions *a* and *b* with higher *L* by different functions. Reduction is greater for *a* than *b* axes, thus improving ellipse circularity with higher *L*. The functions plot straight lines in log-log scale, except *L* below 3 cd/m^2. We give equations to predict *a* and *b* axes, *a/b* ratio, and ellipse area for almost any *L*. These represent a first approach, and with further data may need adjustment. The relative error in predicting actual data from our formulae is similar to inter-observer variability. Effect of *L* is remarkable on ellipse area, which on average halves with every 5 times higher *L*. Clearly, the relative size and shape of *x*, *y* ellipses should be judged only at an equal *L*. Reduced ellipse area with higher *L* is expected, but does not occur in CIELAB and DIN99 spaces due to lack of *L*-level dependency.

1. INTRODUCTION

Commencing with Brown (1951), the influence of luminance (*L*) on chromaticity discrimination has been reported severally. Luo and Rigg (1986) formulated the effect assuming equal effect of *L* on *a* and *b* axes. The effects of *L* have since been reported further and demonstrate that ellipses in CIE *x, y* diagrams reduce size with higher *L* but remain the same in CIELAB. However the effect was not formulated and that on *a* and *b* axes was not differentiated. These effects may bear on current efforts to develop new color difference formulae and color spaces.

The CIE (CIE 1993, Robertson 1978) has called for studies of the effects of *L* on chromaticity discrimination. This paper analyzes (for CIE 1931 and 1964 *x, y*, diagrams) the effect of *L* on axis dimensions *a* and *b*, *a/b* ratio, and ellipse area, for four data sets covering aperture, surface, and simulated surface colors, referred to here as Brown (1951), Melgosa et al. (1999), RIT-DuPont (Berns et al. 1991, Melgosa et al. 1997) and Yebra et al. (2001) data sets. We give equations for each data set, and average equations, predicting *a* and *b* axis sizes as functions of *L* from 3.0-10,000 cd/m^2. Equations for area and *a/b* ratio are also given. The RIT-DuPont ellipses are predicted in *x, y, Y* space at three equal *L*s (42, 212, 2120 cd/m^2).

2. DERIVATION AND APPLICATION OF FORMULAE

We start with a brief description of the four experimental data sets used in the current work. The Melgosa data give the *L* effect on ellipsoids for five color centers each at five *L* levels, on a CRT device, for two observers. Figure 1A shows axis sizes for *a* and *b* in semi-log scale (mean of two observers). Axis dimensions generally reduce with higher *L*, axis *a* more rapidly

60

than *b*, indicating that ellipses becomes nearer circular with higher *L*. In log-log scale, the means of *a* and *b* become straight and represent power law functions. Figure 1B in log-log scale shows power law trend lines for each color's axes. The mean line for each axis, and the power law function (labeled), is found. As power functions, they may be extrapolated to higher *L*. They intersect at 8,200 cd/m^2, implying the mean ellipse would be a circle here.
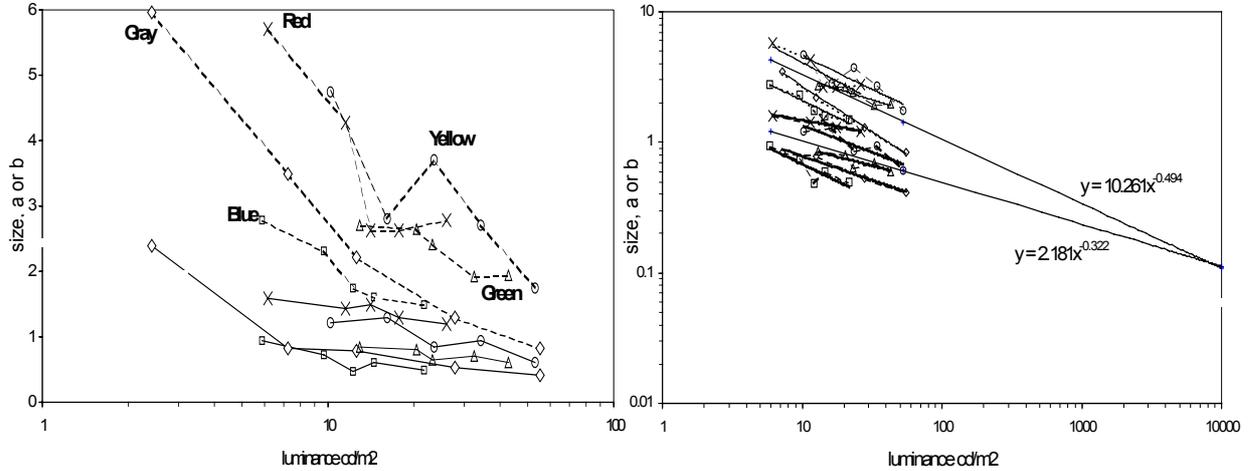
Figure 1. Axes dimensions as a function of luminance, for five centers in Melgosa et al. (1999) data set. A. Major *(dashed line) and* minor *(solid line) axes sizes (100 × actual size) in semi-log scale. B. As A but log-log, with power law trend lines and mean* a *and* b.

Brown's data for his main four colors #4, #19, #31, and #34 (purple, white, green, blue) were similarly analyzed. In log-log scale, the mean *a* and *b* curves remain curved for *L*<2 cd/m^2, and become straight lines for *L*>2 cd/m^2, found to be power law functions. Extrapolated to higher L, they intersect at 8,100 cd/m^2.

RIT-DuPont data do not explicitly report *L* effects but many color centers are sufficiently similar to allow general deductions. The similar chromaticities are: Gray, #3, #10, #18; Cyan, #11, #13, 487-487.5 nm; Blue, #1, #14, 472-476 nm; and Purple, #15, #16, 489-491.5 c. Mean *a* and *b* lines were found as above. Extrapolated, they intersect at 12,800 cd/m^2.

The Yebra data comprise 18 color centers and their color discrimination ellipses for various *L* levels from 2-20 cd/m^2. The data for intermediate *Ls* which are not ≥5 times the minimum available *L* (2.41 or 3.87 cd/m^2) are omitted, as is color center #1 due to large inter-observer variability. Yebra found no clear *a/b* relationship with *L* but when graphed, the mean line for axis *a* is clearly steeper than for *b*. Analyzed as above, mean *a* and *b* curves in log-log scale were found. Extrapolated by their power functions, they intersect at 153,000 cd/m^2.

Table 1 (equations 1-4) gives the mean *a* and *b* power law functions found, as described above, for each data set. All sets agree that axis sizes and *a/b* ratio decrease with higher *L*. This implies that color difference formulae should specify *L* level or (preferably) vary with *L*.

Table 1. Equations for predicting axis dimensions (× 100) in CIE x,y. See main text.

Brown 1951	$a = 1.426\,L^{-0.270}$	Eqn (1a)	$b = 0.467\,L^{-0.146}$	Eqn (1b)
Melgosa et al. 1999	$a = 10.261\,L^{-0.494}$	Eqn (2a)	$b = 2.181\,L^{-0.322}$	Eqn (2b)
RIT-DuPont (Berns et al. 1991)	$a = 8.420\,L^{-0.330}$	Eqn (3a)	$b = 1.650\,L^{-0.170}$	Eqn (3b)
Yebra et al. 2001	$a = 9.359\,L^{-0.339}$	Eqn (4a)	$b = 2.939\,L^{-0.242}$	Eqn (4b)
General equations	$a = 7.366\,L^{-0.358}$	Eqn (5a)	$b = 1.809\,L^{-0.220}$	Eqn (5b)
Relationship coefficients	$A = a_2 / a_1$	Eqn (6a)	$B = b_2 / b_1$	Eqn (6b)

The *a/b* ratio may vary with chromaticity (Luo and Rigg 1986) besides *L*, but a given ellipse appears to vary with *L* by two functions (for *a* and *b*) common to all chromaticities and the data set, and may be predicted thereby. On that basis we formulate (Table 1) the effect of *L* on ellipse axes for each data set as equations (1)-(4), and an average of the four data sets as equations (5), the general equations, intended to represent most situations. Equations (1)-(5) in Table 1 apply to ellipse axis (not semi-axis) sizes × 100. *L* is given in cd/m^2, and *a* or *b* refers to the axis size. These equations apply to *L* from 3.0 to 10,000 cd/m^2, at least, though the slope must level off at some *L* before reversing slope. With further data, these equations may eventuate to represent only a first order of accuracy.

The use of equations 5 is exemplified in Figure 2. Equations (6a) and (6b) give factors *A* and *B* to apply to a given ellipse and *L* to find its dimensions in a target *L*, where a_1 and a_2 denote *a* axis sizes at the original and target *L*s respectively, as found by equation (5a); b_1 and b_2 similarly denote *b* values found from equation (5b); and *A* and *B* are factors by which to multiply the original axis dimensions to predict them at the target *L*. Figure 2A shows RIT-DuPont ellipses at original dimensions and *L*s. Figures 2B-2D show them for three equal *L*s, predicted by equations (5a) and (5b). Note the differences in area and *a/b* ratio with *L*.
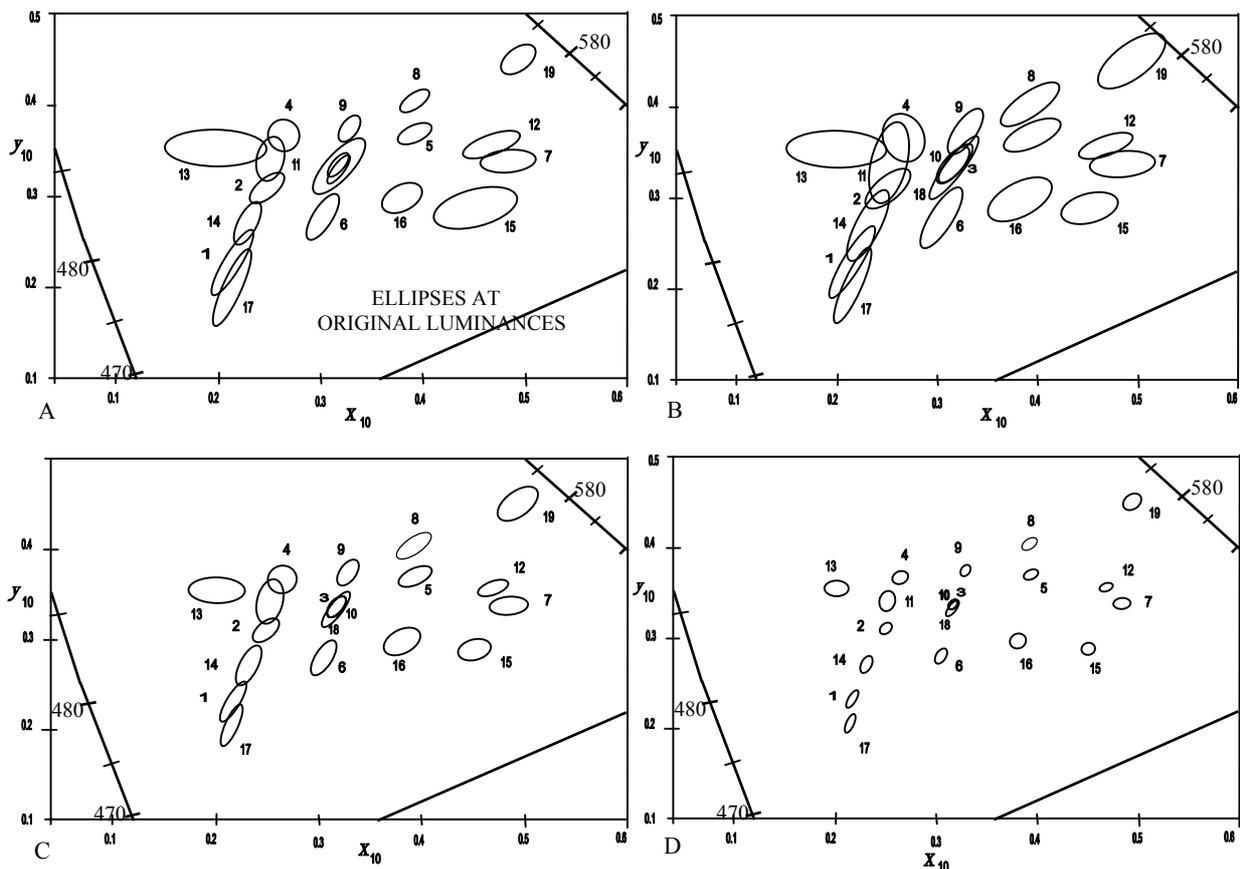
Figure 2. RIT-DuPont ellipses (3 × actual size) (Melgosa et al. 1997). B. Predicted ellipses by factor 6.6 Y (L=42 cd/m^2). C. As for B but for D. As for B but for equal luminance factor 333 *in CIE 1964 diagram. A. Original ellipses equations (5a) and (5b) for equal luminance equal luminance factor 33.3 Y (L=212 cd/m^2). Y (L=2120 cd/m^2).*

A worked example follows. Illuminance for RIT-DuPont data was 2000 lux &&, and the reference white, taken as a Lambertian surface, has *L*=636.6 cd/m^2. Normalized Y_o=100 is employed. Consider RIT-DuPont color #1, *Y* factor 8.67. Multiplied by 100 and divided by 636.6 (or 2000 lux/π) gives *L*=55.2 cd/m^2. Say the target *L* is 212 cd/m^2. The *a* axis is found by equation (5a) for the target *L*, and the ratio of dimensions with respect to the original size

becomes factor A in equation (6a). From Melgosa et al. (1997), the size of axis a for color #1 at 55.2 cd/m^2 was 1.752, and, from equation (5a) at 212 cd/m^2 the size is 1.082. Thus, from equation (6a), A=1.082/1.752, ie, 0.618. Factor A times original ellipse axis a gives its new size at 212 cd/m^2. Similarly, axis b is found from Eqns (5b) and (6b).

Equations (1)-(5) have relative errors similar to inter-observer variability (tabulated data available from either author).

For the general equations (5a) (5b), the ratio a/b (say, D) may be predicted as:
$$D = 4.0725 \, L^{-0.1381} \hspace{3cm} \text{Eqn (7)}$$
where L is luminance cd/m^2. D reduces by 1.374 times whenever luminance increases by 10.

The average relationship to L, for a given RIT-DuPont ellipse in Figure 2, is:
$$(L_2 / L_1)^{0.135} = D_1 / D_2 \hspace{3cm} \text{Eqn (8)}$$
with $L_2 > L_1$, and where D_1 is a/b ratio at L_1 and D_2 the ratio at L_2. Equation (8) predicts D within 3% to D from equation (7).

The average relationship between ellipse area (A) and luminance may be predicted as:
$$(L_2 / L_1)^{0.58} = A_1 / A_2 \hspace{3cm} \text{Eqn (9)}$$
with $L_2 > L_1$, and where A_1 is ellipse area at luminance L_1 and A_2 is area at luminance L_2.

From general equations (5a, 5b), ellipse area A (dimensions $\times$ 100) may be predicted as:
$$A = 10.464 \, L^{-0.578} \hspace{3cm} \text{Eqn (10)}$$
where L is given in cd/m^2. Thus, area A reduces by 2.53 times when L increases by 5, for any L. This is a very large effect. Equation (10) predicts A within 4% to A from equation (9).

Clearly the relative size and shape of ellipses cannot be reliably judged unless at an equal L. Though based on CIE $x, y, Y,$ spaces, the results hold true in general since color discrimination certainly improves with higher L. In contrast, higher L does not reduce axis dimensions in CIELAB or other spaces which similarly lack L-level dependency. Hence CIELAB is factually unable to consistently represent L effects in color appearance.

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Wavelength discrimination thresholds and psychophysical monochromaticity. Definition of the monochromaticity degree

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ABSTRACT

It is well known that a truly monochromatic spectral distribution of radiant flux does not exist in nature. However, when the psychophysical aspect in the perception of a color stimulus is considered, the experimental curves of wavelength discrimination thresholds point out how each wavelength has associated a spectral threshold (undistinguishable region). Thus, the spectral distribution associated with monochromatic stimuli have a certain spectral width. For a given observer, a monochromatic stimulus is characterized by its corresponding associated wavelength and spectral width. In this contribution we propose a systematic method to be used in order to quantitatively evaluate the psychophysical monochromaticity of an arbitrary spectral distribution.

Associated with a given spectral distribution of radiant flux, $\rho(\lambda)$, it is possible to define

$$f(\lambda) = \frac{\rho(\lambda)}{\int_{vis} \rho(\lambda)d\lambda}, \tag{1}$$

where *vis* stands for the intervarl of wavelengths of the visible spectrum.

This function has the properties of a density function, $f(\lambda)d\lambda$ being the probability that a photon of the distribution has an associated wavelength belonging to the interval $[\lambda - d\lambda/2, \lambda + d\lambda/2]$. We can consider that the wavelength associated with $\rho(\lambda)$ is given by the expected value

$$\langle \lambda \rangle_\rho = \int_{vis} \lambda f(\lambda)d\lambda. \tag{2}$$

By following the standard statistical procedure, the width of the distribution will be $\Delta\lambda = \beta\sigma$, where β is a constant and

$$\sigma^2 = \int_{vis} \left(\lambda - \langle \lambda \rangle\right)^2 f(\lambda)d\lambda, \tag{3}$$

being the variance associated with the density function.

Let us consider two nearby distributions, $\rho_i(\lambda)$ and $\rho_{i+1}(\lambda)$, with associated wavelengths $\lambda_i = \langle \lambda \rangle_{\rho_i}$ and $\lambda_{i+1} = \langle \lambda \rangle_{\rho_i}$ respectively. The distance between both distributions is small enough and it is given by $d\lambda$ with $\lambda_{i+1} = \lambda_i + d\lambda$. We are interested in the study of monochromatic stimuli. In this way, we will consider the distributions $\rho_i(\lambda)$ and $\rho_{i+1}(\lambda)$ be narrow enough and with equal widths, i.e.,

$$\Delta\lambda_i \approx \Delta\lambda_{i+1} = \Delta\lambda \ . \tag{4}$$

The situation is illustrated in Figure 1. By considering that the wavelengths λ_i and λ_{i+1} are very close, the question which arises is: when is it possible to distinguish both spectral distributions and their respective associated wavelengths? In order to answer to this question it is necessary to introduce a criterion of physical distinguishability. It is expected the two distributions to be distinguishable between them if their associated functions does not excessively overlap. Taking into account this fact, we introduce the following criterion of physical distinguishability:

$$d\lambda \geq \Delta\lambda \ . \tag{4}$$

This inequality provides a condition of physical distinguishability between two spectral distributions of radiant flux. When the equality is satisfied in expression (4) we will say that distributions $\rho_i(\lambda)$ and $\rho_{i+1}(\lambda)$ are *mutually distinguishable*. If this condition is not satisfied the distributions and the corresponding associated wavelength are not distinguishable between them. The criterion of distinguishability (4) is graphically shown in Figure 2. This criterion is a physical one, in the sense that it is based in the second order statistics associated with the considered distributions.

Figure 1. Two nearby distributions, $\rho_1(\lambda)$ and $\rho_2(\lambda)$, with associated wavelengths $\lambda_1 = \langle\lambda\rangle_{\rho_1}$ and $\lambda_2 = \langle\lambda\rangle_{\rho_2}$ respectively. The distance between both is given by $d\lambda$ with $\lambda_2 = \lambda_1 + d\lambda$.

As it is well known, the curve of wavelength discrimination thresholds of the visual human system, $\delta(\lambda)$, has been experimentally determined. Thus, two given stimuli with associated wavelengths λ_i and λ_{i+1} will appear different between them if $\lambda_{i+1} \geq \lambda_i + \delta(\lambda_i)$. In this way, it becomes obvious that the visual human system imposes a limitation in the distinguishability between two color stimuli with associated wavelengths close enough. In this situation, the curve of wavelength discrimination imposes a psychophysical criterion of distinguishability. Two color stimuli with associated wavelengths λ_i and λ_{i+1} are distinguishable between them if condition

$$d\lambda \geq \delta(\lambda_i), \tag{5}$$

is satisfied. We will say that the corresponding wavelengths are *mutually distinguishable* when the equality holds in this expression.
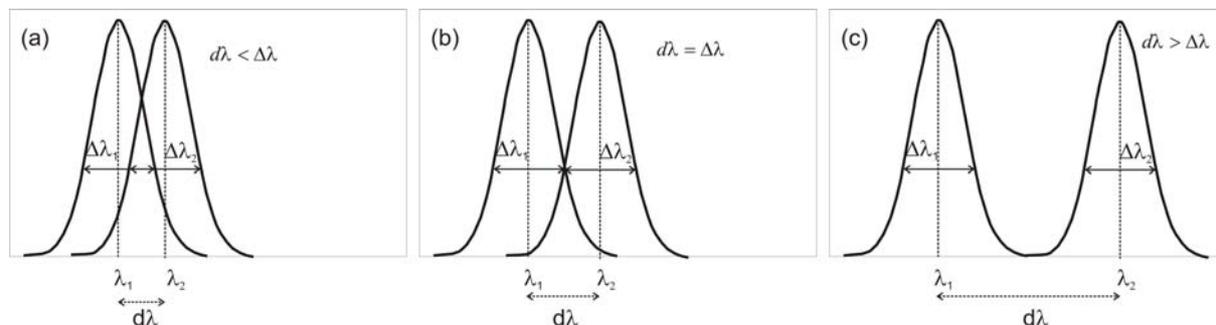
Figure 2. Criterion (4) of physical distinguishability. (a) Undistinguishable distributions, (b) mutually distinguishable distributions, and (c) distinguishable distributions.

From the previous analysis we have obtained two criteria in order to establish if two given color stimuli can be distinguished by the visual system. First of all, we have imposed the criterion (4) of physical distinguishability. It is associated with the shape of the considered spectral distributions. Expression (5) provides a criterion of psychophysical distinguishability, and it is associated with the wavelengths of the color stimuli. In this way, the color stimuli provided by two spectral distributions $\rho_i(\lambda)$ and $\rho_{i+1}(\lambda)$ will only be distinguishable by an observer if inequalities (4) and (5) are simultaneously satisfied.

We now consider a spectral distribution $\rho_i(\lambda)$ whose width $\Delta\lambda$ is obtained from expression (3) and the associated wavelength is given by λ_i. If condition $\Delta\lambda > \delta(\lambda_i)$ is satisfied, we can conclude that the distribution contains more than one wavelength distinguishable by the visual system. In other words, the distribution $\rho_i(\lambda)$ is not associated with a monochromatic color stimulus. The previous analysis suggests us a psychophysical condition of monochromaticity. In this way, we can consider that a distribution $\rho_i(\lambda)$ is associated with a monochromatic stimulus if the following condition is satisfied:

$$\Delta\lambda \le \delta(\lambda_i). \tag{6}$$

This condition of psychophysical monochromaticity imposes an upper limit in the width of a monochromatic distribution $\rho_i(\lambda)$, with associated wavelength λ_i, that is given by $\delta(\lambda_i)$.

Any spectral distribution $\rho(\lambda)$ can be considered as the superposition of M single distributions $\rho_i(\lambda)$ (i=1, …, M) in such a way that $\rho_i(\lambda)$ and $\rho_{i+1}(\lambda)$ satisfy the equality in expressions (4) (mutually distinguishable distributions), (5) (mutually distinguishable wavelengths λ_i and λ_{i+1}), and (6) (monochromatic distributions). We will refer to this set of distributions as *mutually monochromatic stimuli* (see Figure 3).
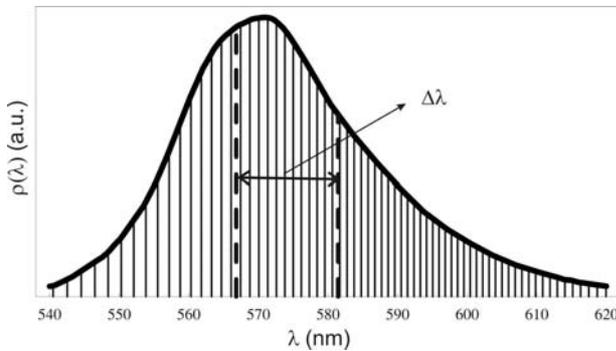
Figure 3. Decomposition of a spectral distribution $\rho(\lambda)$ in a set of mutually monochromatic stimuli. The value $\Delta\lambda$ provides the width of the distribution.

Usually, the experimental measurements of the curves of wavelength discrimination are carried out by using the continuous method. According to this method, the curve $\delta(\lambda)$ is determined in the spectral interval $\left[\lambda_0^\delta, \lambda_M^\delta\right]$, M+1 being the number of distinguishable wavelengths in the visible spectrum, in such a way that condition $\lambda_{i+1}^\delta = \lambda_i^\delta + \delta(\lambda_i^\delta)$ is satisfied. Thus the measured wavelengths, λ_i^δ (i=0, …, M), are mutually distinguishable. We will recur to this characteristic in order to obtain a set of mutually monochromatic distributions $\rho_i(\lambda)$.

Let us consider the experimental curve of wavelength discrimination $\delta(\lambda)$ and two mutually distinguishable wavelengths, λ_{j-1}^δ and λ_j^δ, which are related by condition $\lambda_j^\delta = \lambda_{j-1}^\delta + \delta(\lambda_{j-1}^\delta)$. The spectral interval contained between both wavelengths has a width given by $\Delta\lambda_j = \delta(\lambda_{j-1}^\delta)$ and it is centered at

$$\lambda_j = \lambda_{j-1}^\delta + \Delta\lambda_j / 2. \tag{7}$$

This interval is given by

$$I_j = \left[\lambda_{j-1}^\delta, \lambda_j^\delta\right] = \left[\lambda_j - \Delta\lambda_j / 2, \lambda_j + \Delta\lambda_j / 2\right], \tag{8}$$

and it contains all the wavelengths which are undistinguishable from λ_j. Two spectral distributions centered at the wavelengths λ_j and λ_{j+1}, with spectral widths $\Delta\lambda_j$ and $\Delta\lambda_{j+1}$ respectively, are associated with mutually monochromatic stimuli.

Let P={n(λ)} be the space which contains all the continuous functions defined over λ. We can assume that any spectral distribution $\rho(\lambda)$ belongs to P. To obtain a decomposition of $\rho(\lambda)$ as that shown in Figure 3, we need a base of P containing a set of mutually distinguishable distributions. For this, we will use the M mutually distinguishable wavelengths (7) and the spectral intervals (8). The set of functions (j=1, …, M) given by

$$\varphi_j(\lambda) = \begin{cases} 1/\Delta\lambda_j & if \quad \lambda \in I_j, \\ 0 & otherwise, \end{cases} \tag{9}$$

satisfies the following conditions:

$$\lambda_j = \langle \lambda \rangle_{\varphi_j} = \int_{vis} \lambda \varphi_j(\lambda) d\lambda, \tag{10}$$

and

$$\Delta\lambda_j = 2\sqrt{3}\sigma_j. \tag{11}$$

In this way, the wavelength associated with the function $\varphi_j(\lambda)$ is λ_j and the corresponding width is proportional to the standard deviation σ_j ($\beta = 2\sqrt{3}$). On the other hand, by introducing the usual inner product, it can be shown that

$$\langle \varphi_i, \varphi_j \rangle = \int_{vis} \varphi_i(\lambda)\varphi_j(\lambda) d\lambda = \frac{\delta_{ij}}{\Delta\lambda_i}, \tag{12}$$

i.e., the set of functions $B_M = \{\varphi_j(\lambda)\}$, with j=1, …, M, is an orthogonal one, and it provides a pseudo-base of P. It becomes obvious that it is not possible to exactly generate any spectral distribution $\rho(\lambda)$ by using a linear combination of the functions $\varphi_j(\lambda)$. For this reason we will refer to B_M as a pseudo-base of mutually monochromatic distributions. We have computed the set of functions B_M generated by using the curve of wavelength discrimination provided by Wright and Pitt in 1934. From these data it is obtained that, in the spectral interval [430,650] nm, B_M contains M=145 elements. These functions are shown in Figure 4.
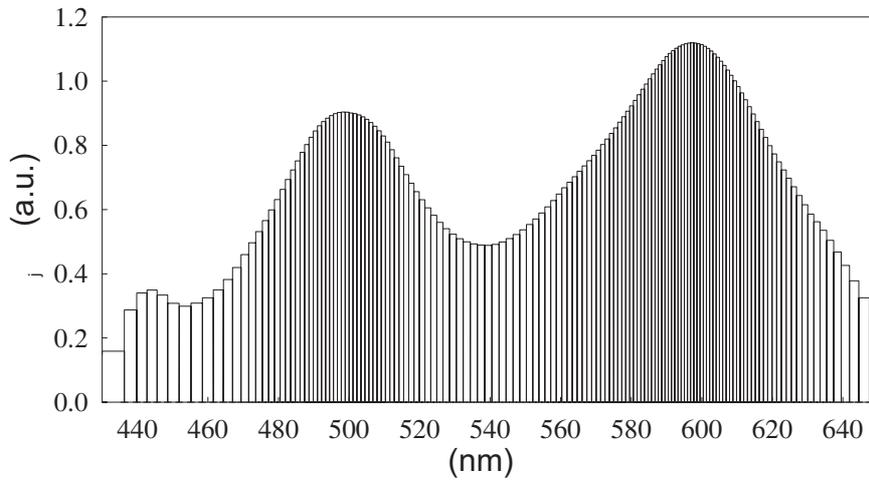
Figure 4. Mutually monochromatic distributions belonging to the pseudo-base B_M obtained by using the curve of spectral sensitivity published by Wright and Pitt in 1934. With this data the number of elements of B_M is M=145.

Given an arbitrary spectral distribution of radiant flux $\rho(\lambda)$, by using the pseudo-base B$_M$, we define the M functions

$$\rho_j(\lambda) = \Delta\lambda_j \varphi_j(\lambda)\rho(\lambda).$$ (13)

With this set of mutually monochromatic distributions it is possible to exactly generate any function $\rho(\lambda)$, as it is shown in figure 3. In order to obtain a quantitative evaluation of the monochromaticity of a given distribution $\rho(\lambda)$, we can consider the number N^p of monochromatic stimuli $\rho_j(\lambda)$ contained in the spectral region defined by its corresponding width $\Delta\lambda$: the larger the number of distributions, the lesser the degree of monochromaticity.

The concept of mutually monochromatic distributions has been introduced by considering physical and psychophysical criteria, expressions (4), (5), and (6). In this way, we define the degree of psychophysical monochromaticity as

$$G^M = 1 - \frac{N^p - 1}{M}.$$ (14)

This quantity varies in the interval [1/M,1] in such a way that G^M=1 when the equality is satisfied in expression (6) ($\rho(\lambda)$ is a monochromatic stimulus).

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Effects of S-cone excitation on color discrimination threshold

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ABSTRACT

It is well known that the short-wavelength sensitive cones (S-cones) contribute to human color vision in a different manner from those of the middle-wavelength cones (M-cones) and the long-wavelength cones (L-cones). We are interested in contribution of S-cones to color discrimination threshold. We measured color discrimination thresholds in several adaptation conditions with different excitation of the S-cone. Increment or decrement thresholds were determined along the directions of $\pm \Delta S$, $\pm \Delta (L+M)$, $\pm \Delta (L+M-S)$, and $\pm \Delta (L+M+S)$ in the $(S, L+M)$ plane of the opponent-color like space; $(L+M, L-2M, S)$. Discrimination thresholds along the S-cone that is $\pm \Delta S$ were elevated with increasing S-cone stimulus values of the background color, but thresholds along the luminance direction that is $\pm \Delta (L+M)$ were independent of the S-cone excitation of the background color. Thresholds along the yellow-blue opponent color direction of $\pm \Delta (S-(L+M))$ did not decrease down to the minimum at an equal energy white background, but decreased with the S-cone component of background color. The increment threshold of S-cone direction $+\Delta S$, was smaller than the decrement threshold $-\Delta S$. We propose a color vision model introducing a nonlinearity in both cone stage and the opponent-color stage to explain the experimental results.

1. INTRODUCTION

Color discrimination characteristic of human vision is very important and useful for both an application for a development of uniform color spaces and an investigation of human color vision mechanism. Many researches on color discrimination have been carried out for a long period. Most of these studies, however, deal with the contribution of the L- and M-cones to the color discrimination. For examples, we investigated the relation between red/green discrimination threshold and the amount of red/green chromatic component of the test color (Yaguchi et al. 2003). Our previous experiments showed that red/green discrimination threshold decreased with decreasing the red/green chromatic component of background color. As concerns the S-cones, it is well known that the S-cone contribute to human color vision in a different manner from those of the M-cones and the L-cones. In the present studies, we focus on the contribution of S-cones to color discrimination threshold.

2. EXPERIMENTS

We measured color discrimination thresholds in several adaptation conditions with different excitation of the S-cone. In the experiments the test pattern were generated on a Sony Multiscan G500 monitor controlled by a Cambridge Research Systems VSG 2/4 graphics

board, with 15-bit luminance-calibrated lookup tables. The spatial profiles of the test patterns are shown in Figure 1. The observer sees a brief flash of the test stimulus with a color slightly different from a steady background color. The background field was a square whose size was 6 degrees by 6 degrees. The test pattern was a square array of four 1 degree squares with a black line separation of 0.1 degree visual angle. Test stimulus was presented in any one of four panes. The subject's task was to report which of the four panes contained the test stimulus.
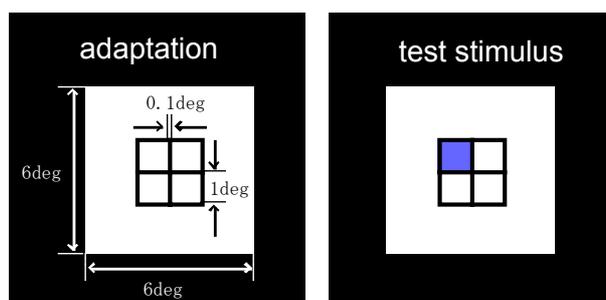
Figure 1. The schematic views of the test pattern.

The temporal profile of the test stimulus was a Gaussian with 100 msec of standard deviation σ. The adaptation conditions were determined by the background colors with different S-cone stimulus values deviated from the equal energy white but keeping a constant luminance. Increment or decrement thresholds were determined along eight directions; $\pm\Delta S$, $\pm\Delta$ ($L+M$), $\pm\Delta$ ($L+M-S$), and $\pm\Delta$ ($L+M+S$) in the (S, $L+M$) plane of the opponent-color like space ($L+M$, L-$2M$, S) on keeping L-$2M$ with zero. Thresholds were determined by the interleaved staircase method.

The excitations of L-, M- S-cones are calculated with the cone spectral sensitivity functions derived by Smith and Pokorny (1975). We defined the cone stimulus values, L, M, S so that $L+M$ is equal to the luminance and L:M:S = 2:1:3 for the equal energy white.

3. RESULTS

The threshold data obtained by the present study were plotted in the opponent-color like space that is the orthogonal space made up of $L+M$, $L-2M$ and S axes. Figure 2 shows the detection thresholds in the (S, $L+M$) plane. These three graphs were obtained by the background luminance of 34.5 cd/m^2 but the different S-cone excitations. The open square of each graph represents the background adaptation color. The shadow square at the right bottom corner of each graph shows the same scale. These graphs show that the thresholds along $\pm\Delta S$ direction elevate with the increase of S stimulus value of background color but those along $\pm\Delta$ ($L+M$) do not change. Figure 3 shows the threshold elevation as a function of S stimulus value of the background color. This graph also shows that the thresholds elevation for $-\Delta S$ are larger than those for $+\Delta S$.
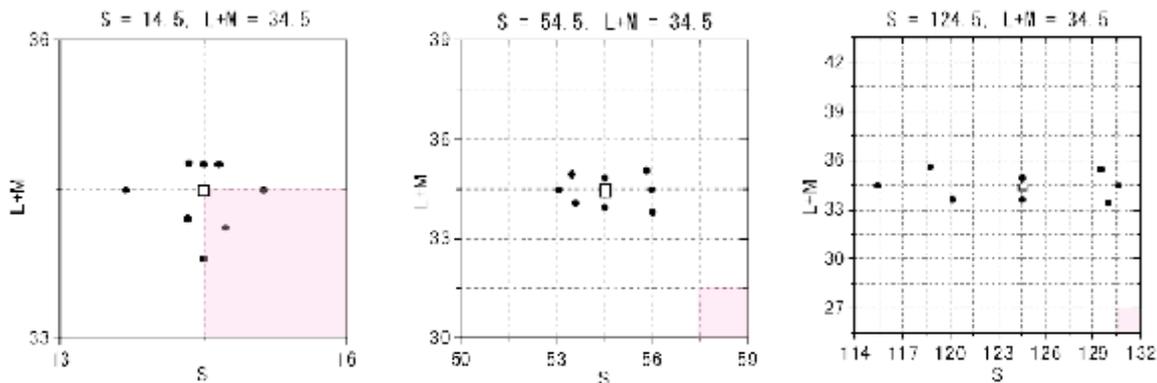
Figure 2. Detection thresholds in the (S, L+M) plane for the subject NW.
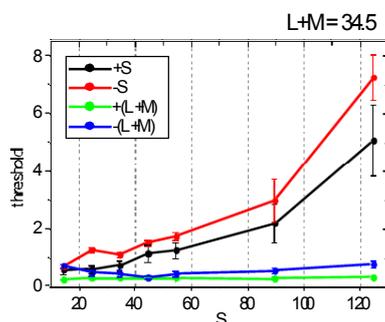
Figure 3. Threshold elevation as a function of S stimulus values of the background color.

4. DISCUSSIONS

From the present experiments, we obtained the following three major results. Firstly, discrimination thresholds along the S-cone, $\pm\Delta S$ were elevated with increasing S-cone stimulus values of the background color, but thresholds along the luminance direction that is $\pm\Delta$ ($L+M$) were independent of the S-cone component of background color. Secondly, the thresholds along the yellow-blue opponent color direction of $\pm\Delta$ ($S-(L+M)$) did not decrease down to the minimum at an equal energy white background, but decreased with the S-cone component of background color. This result is different from the previous result of the experiment where the minimum threshold along the red-green opponent color direction of $\pm\Delta$ ($L-2M$) was obtained at the equal energy white background. Thirdly, the increment threshold of S-cone direction $+\Delta S$, was smaller than the decrement threshold $-\Delta S$.

We modified the model proposed by Smith, Pokorny and Sun (2000) to explain the present experimental results. The model incorporates well-accepted psychophysical concepts that adaptation in cone spectral-opponent channels occurs at multiple stages both before and after spectral opponency as shown in Figure 4.

Figure 5 shows the comparison between the experimental results and the predicted by the model. The prediction by the model introducing adaptation at both cone stage and the opponent-color stage, the graph (a) is better than those from only the cone stage (b) or those from only the opponent-color stage (c).
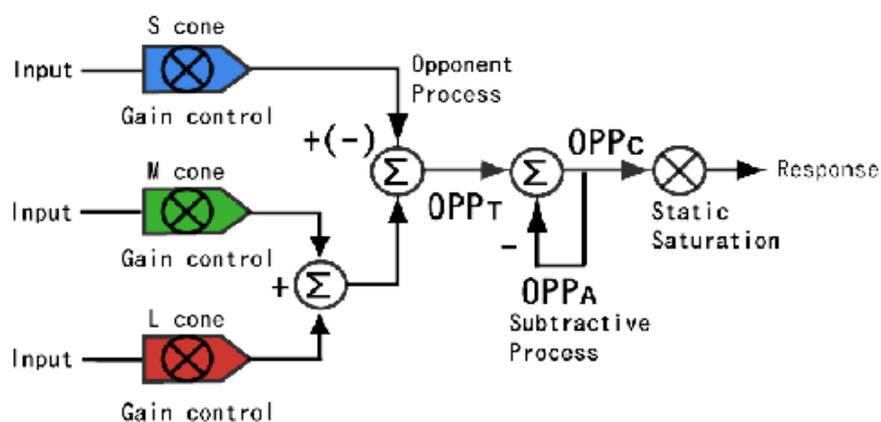
Figure 4. Color discrimination model considering adaptation at both cone-stage and the color-opponent stage.
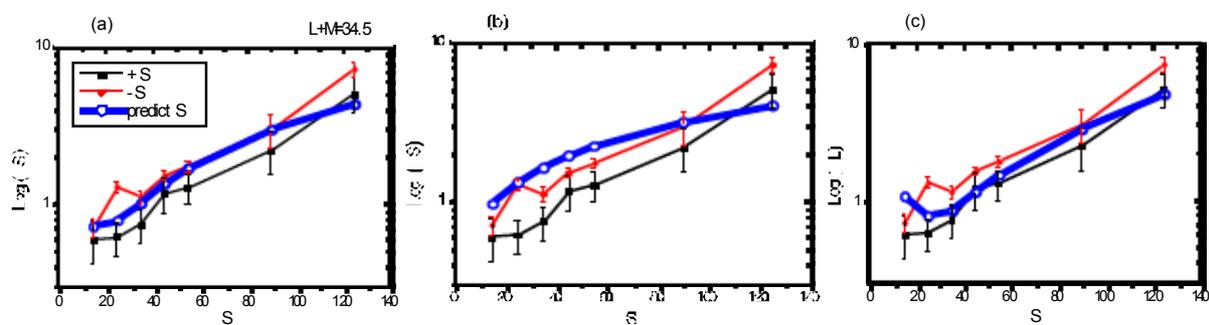
Figure 5. Comparison between the experimental and the predicted color discrimination thresholds of ΔS as a function of S stimulus values of the background color. Adaptation at both cone and opponent-color stage (a), only at the cone stage (b), and only at the opponent-color stage (c).

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Linking painting to visual science:
Creativity versus quantification in the laboratory

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ABSTRACT

Paintings are complex sources rich of multicomponent information, the description of which depends on: a) how it is "read", b) the socio-cultural level of the reader, c) the skill and creativity of the painter. In the present poster we compare the visual vocabulary used when a masterpiece is read from the legal stand point to those used in the biological/physiological, cognitive, semantic, critical descriptions, which involve an escalation across the visual process. It seems to us that the failure of validity of the metrological approach fails during the second stage. At last, we briefly report about our attempt to enlarge the metrological approach, by considering the global description of color appearance in complex, variegated scenes.

1. CREATIVITY IN THE VISUAL ART INTELLECTUAL WORK

The law of copyright enacts that "are defended by this law the intellectual works which exhibit a creative character", by specifying that it refers to its expressivity but not to its content, although possible extensions of the latter cannot be excluded. This is the case of literature (novels, detective stories, etc.) whose plan shows originality, or when the created personages are particularly distinguished.

This concept of the defense of the expressive form is particularly relevant in the case of scientific and didactic works, where the disclosure and reproduction of the content is free, but the copyright, according to the law, concerns the way in which the content is so displayed that it results to be prominent, self contained and self standing.

In the visual figural art (sculpture, painting) the form is permeating the matter, so that "vision" for the painter is equivalent to "concepts" for the writer. These works, like the previously quoted ones, can benefit of the covership offered by the copyright, provided the presentation mode is creative, that is, its orchestration is adequately complex and it is the result of a conscious participation resulting in an "original" form.

In other words, the represented object can be freely reproduced by other painters, provided the latter use different representation modalities —e.g. the ensemble of lines, plans, colors should not be identical with those of the original works. In conclusion, the artwork exists as long as it exhibits a meaningful value, due to a creative effort.

Accordingly, the above-discussed concept of creativity is a peculiar expression of the intellectualization, which implies a novelty, that is, something previously inexistent, hence, not an imitation, but an interpretation.

In principle, it is nowadays unrealistic to create an actually original work, that is, a work not preceded by the traces of similar works previously created by some authors. The question arises what and where the creative cue is to be sought for, that is, the actual novelty, so that a justifiable copyright law could be defined. For this reason, we should:

a) detect and identify the basic cues which characterize the considered work,

    b) compare the above said cues with those of previous similar creations,

    c) decide whether the above said cues exceed the minimum gradient of creativity and novelty requested by the law.

The considered work, susceptible of taking profit of the benefits of copyright, is:

    1) the pictorial elements of the representation are not identical to those of related previous works, in addition,

    2) the artist succeeded in evoking new emotional reaction in the viewer.

2. THE VISUAL VOCABULARY AT THE BIOLOGICAL / PHYSIOLOGICAL LEVELS

The task of visual scientists consists in indicating the factors or mechanisms contributing to the appearance of a painted object (or scene), by considering the related aspects of visual functionality within the metrological framework.

The task of visual artists consists in creating the scene, by using the ingredients of visual functionality, and by entering every stage of the visual process from perception to cognition (Solso 1994). Briefly, painting mirrors the use of the so-called "ecological cues", conveying specific types of information, allowing people to know *where* and *what* is. Now (Gage 2000), it is difficult to relate the general pattern of (color) experience to the specific question of physiology of color vision. It follows that paintings may be described by the use of metrological assessment (potentially performed by a machine inspired to computational vision), but having in mind its limitations.

In the recent literature (Solso 1994, Lamb and Bourriau 1995, Gage 2000, Livingstone 2002) one finds the careful analysis of several paintings, referred to the various stages of optical processing. Going through these books, we picked up the identified terms of the visual vocabulary. Their list, concerning the first two stages of visual process (stage 1, eye: transduction, edge detection; stage 2, brain: visual cortex, primitive processing of line edges, shapes, form analysis, featural analysis of primitives) are listed below:

Appearance, local, global, transparency, luster, gloss. Capacity of processing visual information, details and texture analysis. Color, complementary colors (juxtaposed), color opponency, color and light (SPD), color and form, shaping colors, color orchestration, harmony, visual weights, visual balancing, colored shadows, chromatic symbolism, color deficiencies and disabilities. Contrast, assimilation, induction, achromatic vs. chromatic contrast, pop out, contrast and symmetry, context effects. Edge, borders, contours, outlines, boundaries, sharp edges, gradients, ramps, Mach bands, blurring vs. desaturation, spread effects, filling-in visual acuity, its eccentricity dependence, spatial distribution of blur, border enhancement and apparent (3D), undefined borders, blurriness, shading. Eye movements, visual perlustration, image at a glance. Gratings, repetitive patterns. Irradiation. Luminance, brightness, lightness and their spatial distribution, equiluminance of heterochromatic objects. Optical illusions, apparent movement, *trompe l'oeil*, jitter, vibration, impressions of transience, ambiguous, reversible figures, etc. Perceptual organization, segregation, segmentation, internal representation (with occluder, figure-ground grouping), preconscious perception, abstract art. Perceptual constancy, discounting and not discounting the illuminant. Perspective, aerial, linear, apparent (3D) on canvas, depth sensation, space sensation, distance perception, C. W. Tyler autostereopsis. Visual spectral sensitivity, photopic, mesopic, scotopic vision. Texture, texture borders, segmentation. Perceptually uniform gray and tonal scales.

It is auspicable that the above listed terms, the majority of which is covered by the umbrella of metrology, might be of some help to those who are involved in the quantitative description of visual art works for legal purposes.

3. THE VISUAL VOCABULARY BEYOND THE METROLOGICAL BARRIER

In the literature quoted by us, the descriptions of paintings call into play cognition, thus entering the stage 3, brain, semantic processing throughout the cerebral cortex, the motor cortex and other areas: semantic processing, associations with existing knowledge, etc. The vocabulary covers now terms, listed below, which are only indirectly related to the properly said visual vocabulary (see section 2).

Scientific and artistic explorations are considered the most intimate inquires into the structure and operation of the mind. Art is more than paint smeared on a canvas. It is a glass in which the human mind is reflected. The vocabulary covers now terms which are only indirectly related to the elementary treatment mirrored by the vocabulary reported in section 2. The list of terms picked up from the books of Solso (1994), Lamb and Bourriau (1995), Gage (2000), and Livingstone (2002) includes: aesthetics, ambiguity, associative elements and color sensations, atmosphere, ambience, magic, mysterious, misty, dramatic, gentle, soft, dreamy, theatrical, realistic, dynamic, cognitive processes, coherence, incoherence, complex, resonant aspects of a painting, conceptualization, conflicting factors, dissonance, dynamic tension, errors of logic, expressive character of color, interactions, excitatory, inhibitory, interest, lively, meaning (semantic value), mood, oppression, irritation, emotion, serenity, fantasy, softness of dream, strength of a painting, surrealism, symbolism, allegories, synthetic intellectualism, talent, vitality.

4. THE LANGUAGE OF ART CRITICS AND THE NEW FRONTIERS

Beyond the featural and semantic interpretations, there are those inspired to universal properties of the mind, often used by art critics, with their specialized language, very far for any direct or indirect metrological approach, hence not considered here.

However, it seems worthwhile to recall that the advanced research is involved in modeling some functions of the higher centers, so that, in the future, some vague descriptions of global appearance could be concretized. This is the case, for instance of sentences like (Solso 1994): "according to this freedom of expression, objects are windows to the mind of their creators"; or "Kandinsky, while attempting to produce a pure painting, aimed at energizing geometric forms with a spiritual meaning"; or "Some picture constructions bear a close resemblance to what has been discovered about human information processing of visual events; our memory of an object is not based on a series of snapshots we have neatly filed away in memory stored … but of salient and meaning features stored in the memory as an abstract representation of that class"; "Canonical representations, that is, memories that best represent the concept of a class, are 'central views' of an object, a person, an idea, expressed in mental images activated when a theme or subject is mentioned … they may also be expressed as an abstract representation of that class", and so on.

5. OUR EXPERIMENTAL CONTRIBUTION:
AN ATTEMPT TO ENLARGE THE METROLOGICAL RANGE OF DESCRIPTION OF COLOR APPEARANCE IN PAINTING

Because of the obvious constraints in the allowed space, a detailed report of our experiment will be displayed in the poster, while here we limit ourselves to a scheme of our research program.

The global color appearance of complex, variegated scenes cannot be deduced from the set of local color assessments. Usually, reference is made to linguistically based polar contrasts like cool versus warm, light versus dark, monochromatic versus polychromatic, etc.

As an alternative, we considered the overall complex form as fabricated of simpler forms (Solso 1994), a method borrowed from the methods of computerized pattern recognition. We identified the relevant objects represented in the considered painting (e.g., skin or flesh, trees, etc.) and we categorized their color with traditional methods.

As another alternative, we performed the so-called "scene analysis". The spatial frequency spectra and the area-weighted histograms of local categorical colors, including hard-to-name colors are found to vary smoothly along the continuum delimitated by abstract art on one side, and representational art on the other side.

At last, we adopted the determination of the visual balance condition, as a global evaluation of the "deviation" of a colored image both from gray and from spatial uniformity, the visual balance condition. The descriptive potential of this alternative, on a quantitative scale, seems to be very high.

6. CONCLUDING REMARKS

"Creativity" may be defined in various ways, e.g., a quality, a dimension of the personality of an artist; a new innocence of perception, liberated from the cataract of accepted belief; the freedom of using our own language, or the capability of creating a new language, etc.

From our review, some vocabularies emerged; it is hoped that some of these terms might be of help for quantitative, creativity related, descriptions. In any case, no general rules seem to exist, and the case-by-case treatment is recommended.

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Psychophysical study of colour

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ABSTRACT

Colour plays an important role in many practical tasks related to choice, identification, and as linguistic element of the visual communication system. Colour memory is also one of the factors responsible for the phenomenon of colour constancy. Psychophysical methods and procedures are useful in determining threshold, including visual field analysis. A psychophysical experiment was carried out for describing colour appearance under different viewing conditions. Measurement of visual response can be achieved through several methods. In this paper the method of constant stimuli is applied. Analysis were made on the base of comparisons with visual evaluation as well as instrumental CIEL*a*b* evaluation (L*, C* and H* colour values). Yellow and blue hues were the chosen samples. Yes or No response presents a stimulus. Correct response can range from 0% to 100% as shown as stimulus intensity vs. percentage seen. Results obtained, presented in a CIEL*a*b* through C*/L* and a*/b*, showed more disagreement of visual evaluation compared with instrumental evaluation in the area of yellow then blue hues.

1. INTRODUCTION

Psychophysical methods were used by pioneers in the field of sensory research, such as Aubert, Exner, Helmholtz, and Hering. Von Kreis, Mach and Weber, and provided the basis for many fundamental insights into and understanding of sensory mechanisms (Jung 1984).

The three major colour vision theories which are the basis of colour science and modern colorimetry are the trichromatic theory of Young and Helmholtz, Hering's opponent colour theory and the retinex theory put forward by Land. These theories generally defining colour as the result of the total amount of luminance energy reflected from the colour surface, which stimulate photosensitive receptors in human eye. CIE tristimulus values X, Y, Z uniquely defines the colour in numerical and precisely describe the colour. X, Y, Z values represent basic spectrophotometric data which are calculated into different colour parameters through means of different mathematical models (Wyszecki and Stiles 2000, Parac-Osterman and Joanelli 2001).

Modern work procedures and the definition of colour space are determined by CIELAB values L*, a*, b*, C* and H* of dyed samples (McDonald 1987).

A psychophysical experiment was carried out for describing colour appearance under different viewing conditions.

In this paper analysis were made on the base of comparisons with visual evaluation as well as instrumental CIEL*a*b* evaluation (L*, C* and H* colour values). Obtained statistical survey of observers experience intensity of colour and influence of the background at visual evaluation is noticeable.

2. METHODS

All experiments were carried out on samples of yellow and blue hue. The samples were put in order according to saturation (eight samples per hue, size 2 × 2 cm).

Samples were measured in CIELAB mode spectrophotometrically by means of DataColor type SF 600+CT remission spectrophotometer, D_{65}, d/8°. Results were obtained employing C*/L* and a*/b* relationship and were presented in a form of graph.

Psychophysical study of colour samples of colour was carried out among 25 observes (age 20-40). Visual evaluation was carried out in a colour match box according to standard of light source D_{65}. In purpose of these experiments samples, sized 2 × 2 cm, were put on grey, blue or yellow background according to saturation. Observers ranged samples from 1-8 (number of samples) for any background according to lightness, hue, and saturation (as constant stimuli of observers). Conclusions were made based on statistical analysis of obtained data and presented as coefficient variation were given as percentage (V %):

$$V = (\sigma / \overline{X}) \, 100 \qquad \sigma\text{- the standard deviation, } \overline{X} - \text{the mean for the samples.}$$

3. RESULTS

Figure 1 shows the colorimetric properties of coloured samples on the a*/b* plane. It is noticed that blue samples, after no. 5, change hue for 12^0 (H*255-243^0).
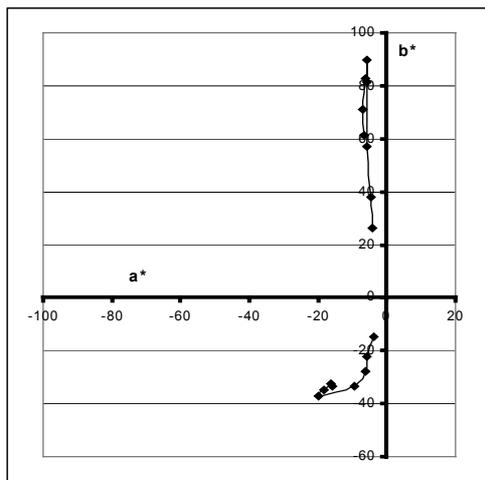
Figure 1. Colour position in a/b* plane.*   *Figure 2. C* and L* value of samples.*
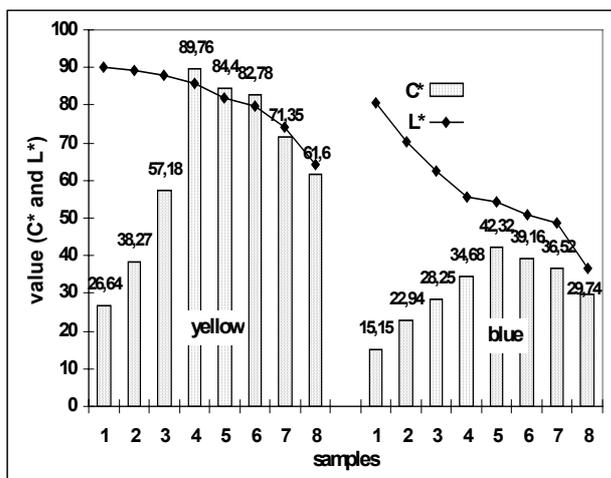
Figure 2 gives the relationship C* and L* value of samples. Colour depth is also influenced by hue. The contribution of chrome and light in yellow area are the highest, but that in blue area is the lowest.

Figure 3 and 4 give statistical survey of observers colour hue experience intensity (calculated as coefficient variation V) in relation to background of evaluated hue and presumed intensity of samples.
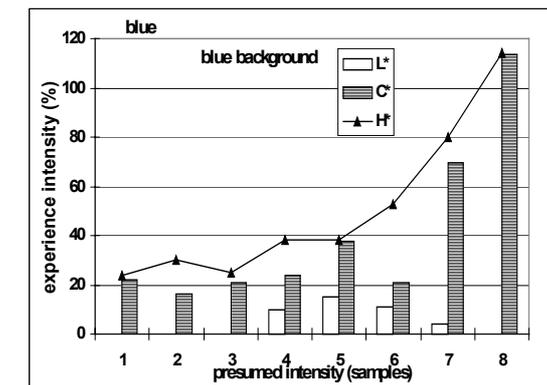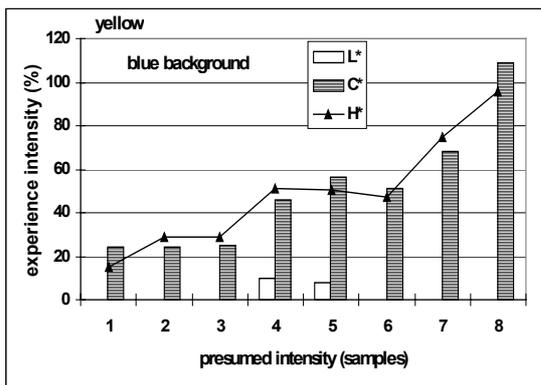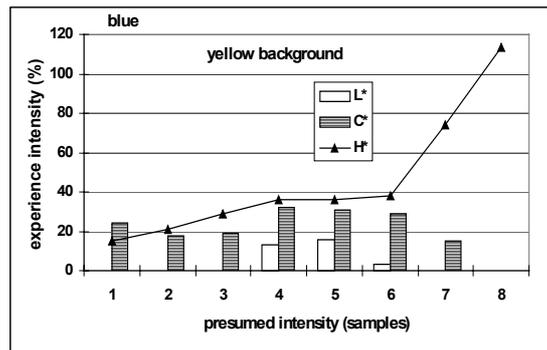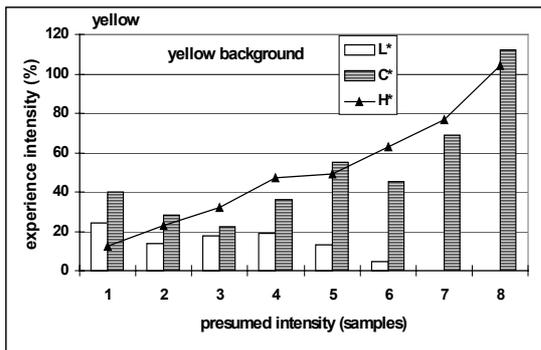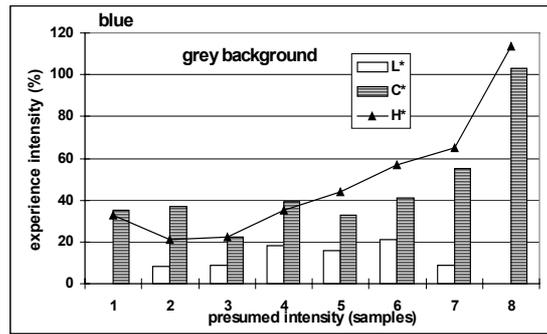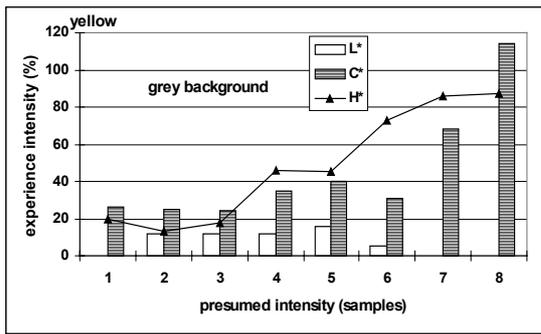
Figure 3. Influence of the background on experience intensity yellow hue.

Figure 4. Influence of the background on experience intensity blue hue.

4. CONCLUSION

Computerized-instrumental methods of colour measurement are based on tristimulus values (X, Y, and Z) and define colour by means of colorimetric values, L*, C*, H*, a*, b*. These values are objective and are not influenced by the surrounding elements or the observer.

Analyses in this paper were performed on a group of blue and yellow hue (complementary relationship) with growing chroma value respectively.

Based on colorimetric values (L*, C*, H*, a*, b*) obtained by instrumental measurement of coloured samples, showed on Figure 2. It can be assumed that in the range of smaller lightness and chroma differences of the identical hue, the subjective sense of colour would be influenced by the observer and surrounding elements.

Based on C* and L* values showed on Figure 2, major discrepancies of subjective visualisation can be expected for the samples 6, 7 and 8, more significantly for the yellow hue.

It has been proved that the intensity of observers' visualisation of colour in dependence of the backgrounds colours, can be defined through the value of variation coefficient (measurement of the samples dispersion %), for the constant values of H, L and saturation (C).

The influence of the background colours is more significant for the group of yellow samples (observed on the blue background).

The experience of blue and yellow hue on grey background (with the exclusion of sample no. 8) is complete by all three psychological colour attributes (H, L, C). Obtained values were in correlation with instrumental measurements (Figure 2).

In general, lower values of variation coefficient, obtained for lightness stimuli, accented for the samples of higher chroma values, proved the dependence of the psychological experience of colour on hue and chroma parameters.

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TECHNOLOGY, COLORIMETRY, ORDER SYSTEMS

Appearance in paints:
Gloss, spatial filtering and definition of image (DOI)

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1. REALITY

The real world is perceived through our senses. Of them, the more important is, beyond any doubt, sight. Our eyes are wonderful appendixes which detect images of this world and *give meaning* to reality. That reality is but *our* interpretation of it. Each person sees what he can or wants to see, and on it not only the eyes take part, but all the nervous system which transmits the signals from the eyes to the brain which *understands* those signals. In this process several factors take part: the individual characteristics, our experience, our prejudices our habits, in sum, everything which make us human beings.

In each eye there are about 130 million detectors (cones and rods) which generate signals through nervous cells (bipolar, ganglion, etc.), which are conducted through approximately 1 million axons which conforms the optic nerve. The optic nerve of each eye drives to the optic quiasma where joints and immediately divides as the left and right vision arms going to a part of the brain called lateral geniculate body where the optic nerve ends in a special encephalic mass which beneath born other ends of nerves which are directed connected to the visual cortex of our brain. In this visual cortex is where the images we see are reproduced and understood through our personal interpretation.

As each person sees *his reality*, and that not necessarily agrees with others, therefore it is necessary to establish parameters and rules to be able to compare what different people see when they are looking the same object or phenomena. Among the visual phenomena that usually see is the appearance of objects or materials. This appearance has defined variables which not always have the same interpretation. For example, gloss and some related phenomena as haze, lustre, shininess, definition of image, etc.

This paper has the purpose to help to understand these phenomena and try to establish parameters which allow us to evaluate these phenomena in the most possible objective way, being independent, if possible, of our personal particularities. In other words, to try to evaluate reality as it is and not as we believe it is.

2. GLOSS

Gloss is related to the polishing degree of a surface. When we look an automobile in the window of a dealer we see the illuminating lights of the room (or the sun if it is daytime) to be intensely reflected in some place of its surface. The owner of the place has been careful to ask some dependant to clean the dust to eliminate any spot which can affect the appearance of the car paint. He knows that on this appearance depends the attraction of the merchandise he offers.

How is gloss detected? It is a consequence of the material surface property to reflect the specular component. That is, as if we were dealing with a mirror. If a new car goes in a country road without pavement, its gloss will disappear soon as result of earth particles adhered on the surface.

In the same way as a mirror in the bathroom is swaddled because the deposition of small drops of water, not allowing to see us reflected in the mirror, the dust of the road deposited of the surface of the car impedes to see its gloss. The light is not lost, but *diffused*. That is: directed towards other directions different than specular.
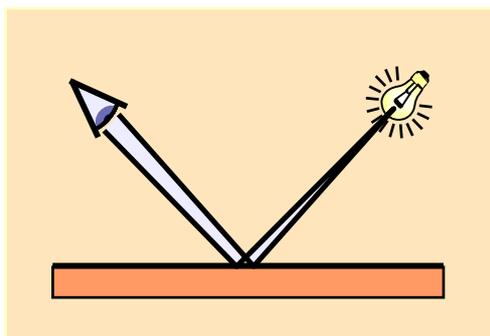
Figure 1.

In the schema of Figure 1 a lamp light illuminates at 45° approximately a plane surface, and the reflected beam at the same angle is seen by the eye of an observer. If that surface is a mirror or is polished, then the observer will see the light reflected in the surface and will say that that surface is *glossy*.

There are several geometries to measure gloss. Normally 20°, 45°, 60°, 75° and 85° are used as incident and measurement angles. Most used in the paint industry are 20°, 60° and 85°. Normally, gloss is measured at 60° and if the lecture is inferior to 10 then 85° must be used. If higher than 70, then 20° must be used. This follows the Standard ASTM D523-89: *Specular gloss*.

It is very important to chose the measurement geometry as the incident and reflection aperture angles (Standards ASTM D523-89 and ISO 2813:1994, *Paints and varnishes - Determination of specular gloss of non-metallic paint films at 20 degrees, 60 degrees and 85 degrees*). Differences in the strict observation of these Standards give place to significant differences among values measured with different instruments of the same sample, even when both are calibrated according their own procedures.
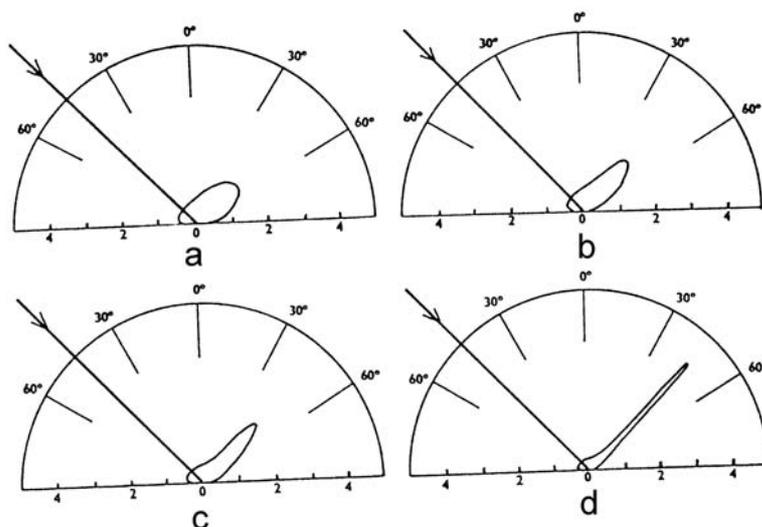
Figure 2.

To understand this effect it is necessary to know that the light reflected by a surface is related with the finishing of that surface and the reflection is not completely diffused or specular. If one uses a goniophotometer to measure the spatial distribution of the reflected light around the point of the light incidence, as for example in Figure 2, the effects of different type of paper finishing can be appreciated: a) catridge, b) super calendered, c) brush coated art, and d) cast coated (Adams 1965). As it can be seen, the specular component grows and the curve is sharpened pointing in that direction. If the optical apertures are different, then the results will vary depending on the size of it, and whether the whole peak is included or not. This can be better understood in Figure 3, where two different cases are drawn.
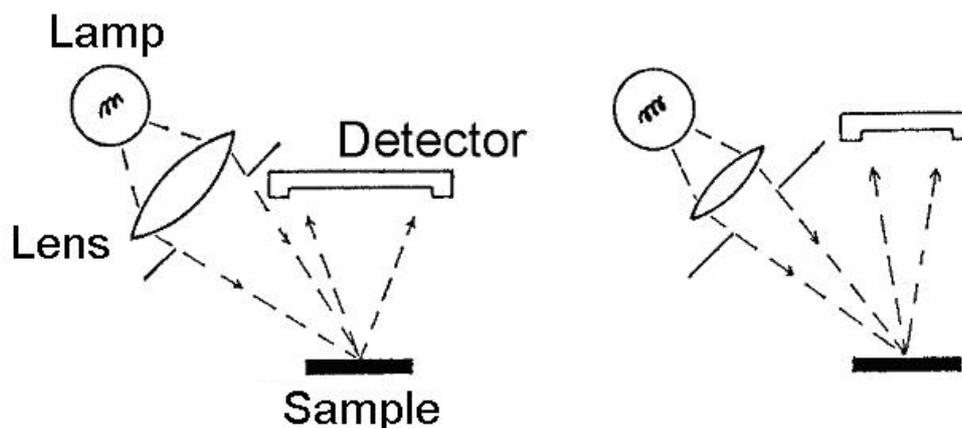
Figure 3.

In Figure 3 the right aperture is smaller than the left one. If the reflection *indicatrix* (the term used to describe the goniophotometric curve) has a step peak, as shown in case d) of Figure 2, the result of both geometries will not change substantially, but if the material is diffusing enough, as in cases a) and b), the results will differ due to the fact that the acceptation angle (or the receptor aperture) will limit part of the curve and the other will not.

Metals are normally measured with an angle of 45° and papers with 75° (Standard Tappi T-480: *Specular gloss of paper and paperboard at 75 degrees*), though for very glossy papers a geometry of 20° is used (Standard Tappi T-653: *20° specular gloss of waxed papers*).

Metals, and in general, surfaces with metallic appearance, are characterized by an special appearance mode, of which people can identify which matter is, but, in general, they do not know why. Not only metallic surfaces have a high gloss (if they are polished) because its hard surface allow to reduce irregularities to light wavelength size, but also, because for different angles the spectral reflection changes, that is, it has different colours depending on the observation angle. For this reason it is important for an observer to see the surface bent, or if the surface is plane, that has an enough extended area to be able to see this effect. For this reason metallic paints are measured with a spectrophotometer with different incident angles. Figure 4 shows a case of bronze paint in which the different spectral reflection factors were measured for different angles of the measurement angle.

The incident angle is 45°, and the measurement one depends on the instrument used. Optronic has an instrument with 9 different angles, Macbeth 4, but two possibilities (with 15°, 20° or 25°), 45°, 75° and 110°, X-Rite measures with 5 different angles: 15°, 25°, 45°, 75° and 110°.
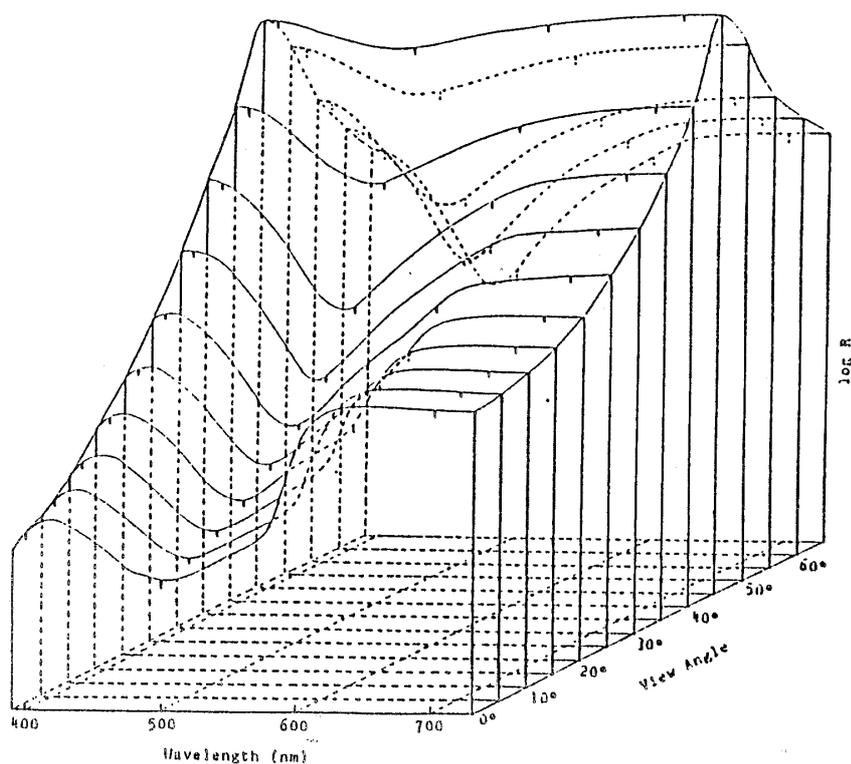
Figure 4.
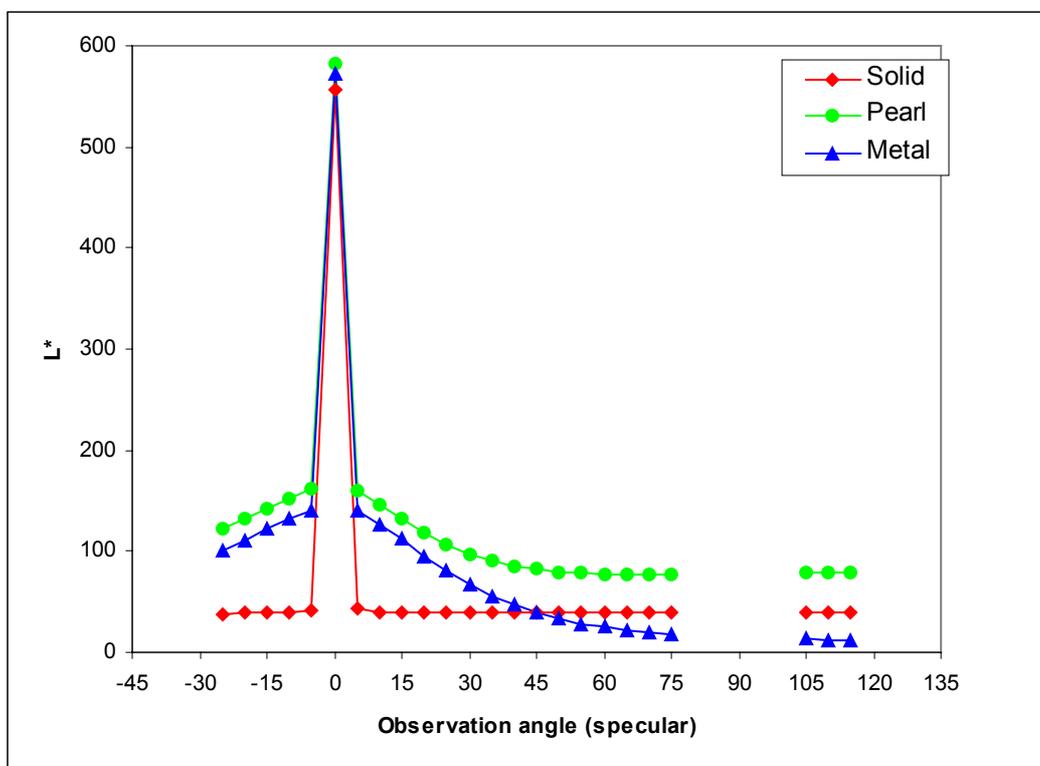
Figure 5.

Figure 5 shows the effect of the same solid paint for different substrate (metallic, pearl or normal) on the gloss peak. While for a normal paint the gloss is defined very closed (just a few degrees, about 3°) to the observation angle, metallic appearance grows since 120° from both sides, and pearlescent paints does from 60°, but has a higher reflectance factor than the other two and grows more from 45° onwards, and therefore increasing the tristimulus value (CIELAB) L*.
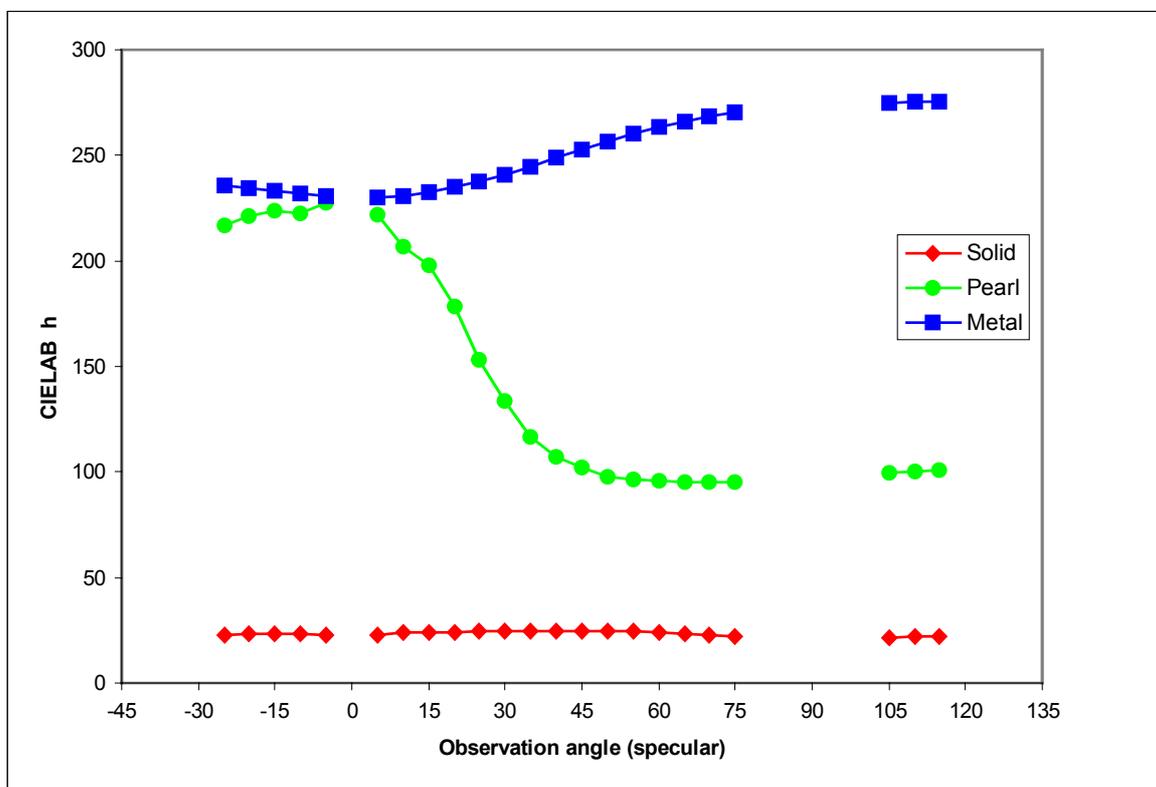
Figure 6.

In Figure 6 it can be seen that not only the spectral reflectance and its lightness change, as in Figure 5, but also its perceived colour. While the sample of solid paint (without effects) keeps constant the hue angle (CIELAB) h, in the pearl paint changes are dramatic passing from turquoise (h ~ 220°) to yellow slightly greener (h ~ 100°), while in the metallic case, drifts the colour in the contrary sense, turning it to blue (h ~280°). This chromatic variation has been called "flopping" by Altman (1987).

3. DEFINITION OF IMAGE (DOI), HAZE

When one looks an image in a mirror one expects to see borders very well defined. If, for example, as we said before, in a bathroom the mirror is swaddle while the hot water shower is open, the defined lines or our faces initially reflected on the mirror tends to vanish. This effect is called definition of image or DOI. The same can occur if on a glossy surface, as a paint, a fine grain sandpaper is applied; then the image become turbid and without definition.

There are photometric methods to evaluate quantitatively haze and definition of image. With this purpose, reflectance is measured at angles very close to the specular reflection. The instrument *Dorigon*, produced by Hunter Ass., measures DOI at ±0,3°, that is 18' respect to

that direction (Hunter and Harold 1987). Other instruments measure haze at 2° and 5°, and some other measure at 15° what is called *diffusiveness*.

In Figure 7 the definition of lines and vertical cylindrical columns of the building is clearly appreciated, and one can evaluate that the car paint has good definition of image. In Figure 8 the same picture shows a worse definition of the building image.

Figure 7.

Figure 8.

The clue for this complex evaluation is to see how the lines reflected are defined. They can be more or less blurry, more or les deformed. The subjective evaluation of the observers will depend on the criteria applied, their own experience and the roles to follow.

This is an important point to consider. How is made an evaluation of this type? In the first case, the criterion followed is called "image quality".
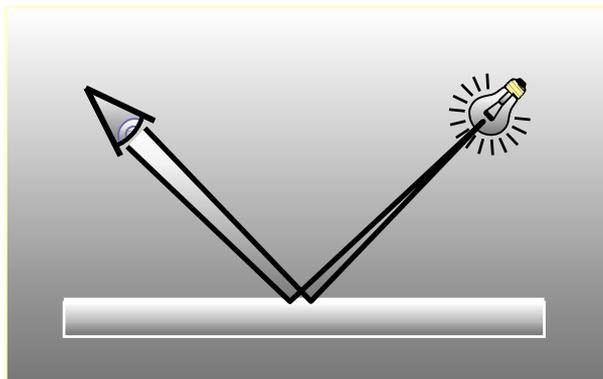
Figure 9.

In Figure 9 one can see that the light reflected is observed. Otherwise, in Figure 10 one pay attention to the whole image reflected. In other words, one is aware to see if lines are well defined or not.
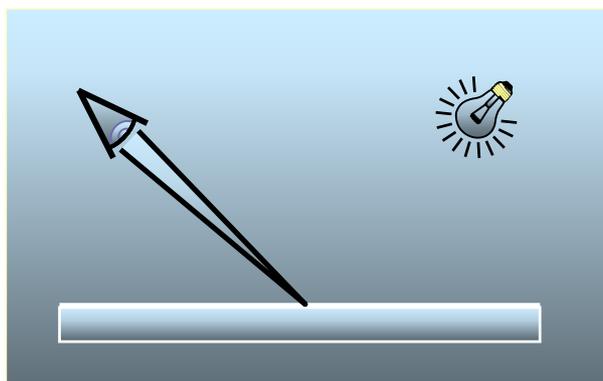
Figure 10.

In that case people are observing the *surface structure* and not the image. They pay attention to the finishing of the surface, detecting rugosity or polishing, the image distortion. In Figure 11 it is possible to see a painted red board where all defects here mentioned, definition of image (DOI), graininess, polishing, orange peel, gloss, appear.

Around the lines of the reflected squares some of the mentioned effects can be seen, and the image is more explicit than many verbal explanations. It can be seen the surface shininess as the poor line definition, which allows to think that there is orange peel and good gloss. That is: a polished surface, but irregular.

In Figure 12 magnification of the reflection lines can be seen for three different kind of paints, and from lower to higher it is possible to see how the diffuse line of (a) grows narrower and wider in (b) and become deformed lighted isles in (c). These defects or deformations of the reflected image can be due to different reasons, such as the lack of fluidity, levelling, dryness, etc., which will not be deal with in this work, but can be identified with good resolution.

Figure 11.

(a)

(b)   (c)
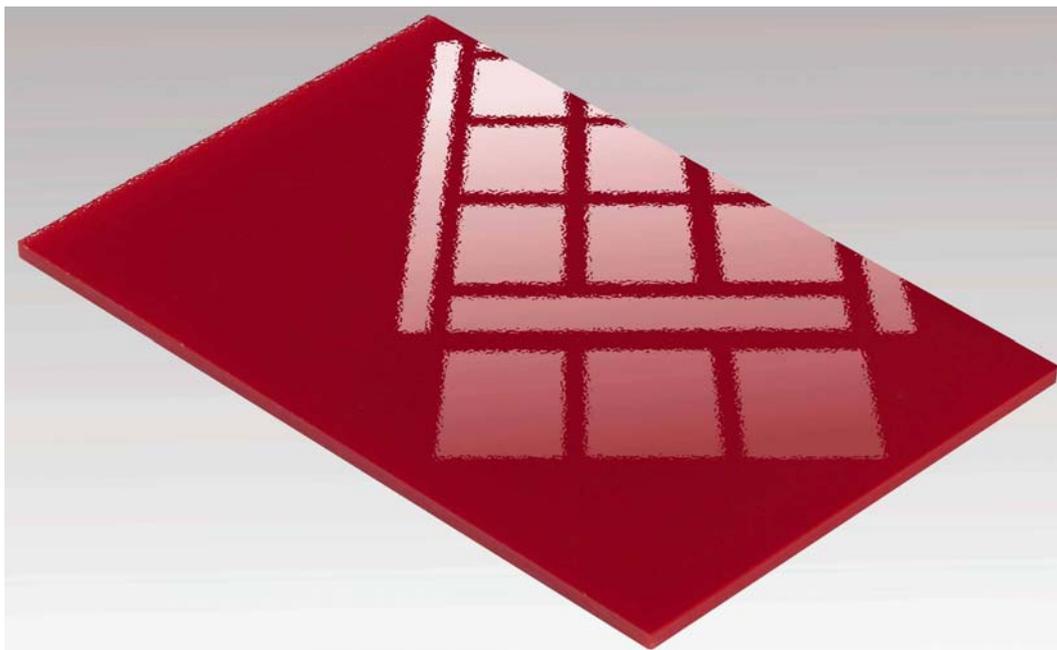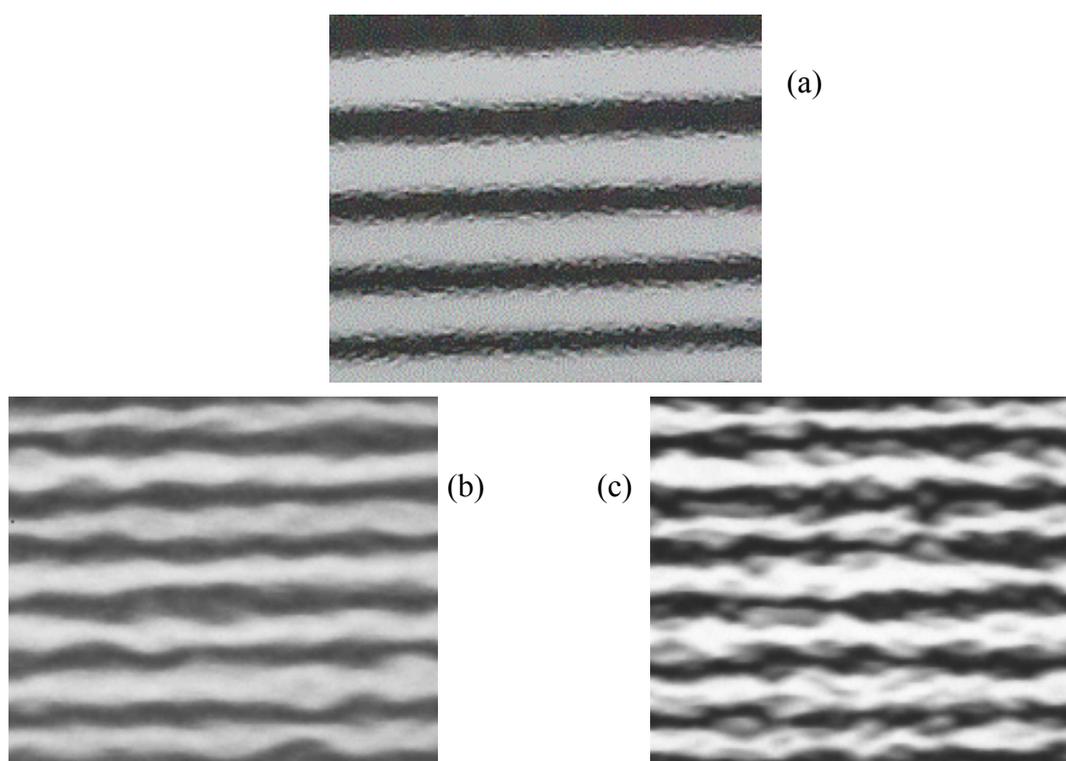
Figure 12.

It is important to remark, before to continue, what has been said by Czepluch (1987) in the same symposia where Altman proposed the flopping, and Hofmeister (1987) showed how pearlescent paints varied with the observing angle. Czepluch thinks that the general appearance is not only a part of what is evaluated by the human eye, but also due to the fact that human beings sees binocularly simultaneously, implying that each object is being seen by two eyes, not one.

To this it must be added the fact that to be properly evaluated, such surfaces need to be illuminated with directional lights (on the contrary to diffuse illumination), or surfaces must

be curved, to reflect lines as in the previous buildings, and thus one can perhaps understand a little more that thing called *appearance*.

A later analysis will show that this perception of lack of definition of image and its deformation can be thought as decomposition of image into spatial frequencies and its transmission through the reflection of the considered surface, but this is a matter which will be treated later on in this paper. Let us see now what is that effect called orange peel (see also Carmak and Verma 1987).

4. ORANGE PEEL

All people, at least the majority, know oranges and their peel or cover which is similar to that of lemons, mandarins, etc. (citrics, in general). If people are required to define it *verbally*, they are in problem. They know what we are talking about, beyond any doubt, but we have not the experience, nor the language, neither the mathematical tools to be able to describe it.

It is not the unique case, on the contrary, very often happens that we talk about common things which we cannot describe properly without mentioning our memory or experience. This phenomenon is similar because one tries to describe its surface appearance based on *similarities* with something else, and not based on what it *really* is. Eye, eyes, and our mind elaborate the answer comparing registers in our memory and then define what is seen. How?...Why?.... We do not know.

This is the subject being discussed, from an indirect way, through a physic-mathematical mechanism known as spatial filtering, or optical transfer function (OTF).

5. SPATIAL FREQUENCIES AND SPATIAL FILTERING

What is the meaning of spatial frequency? Figure 13 shows four frequencies of *nets* drawn with lines of different thickness.
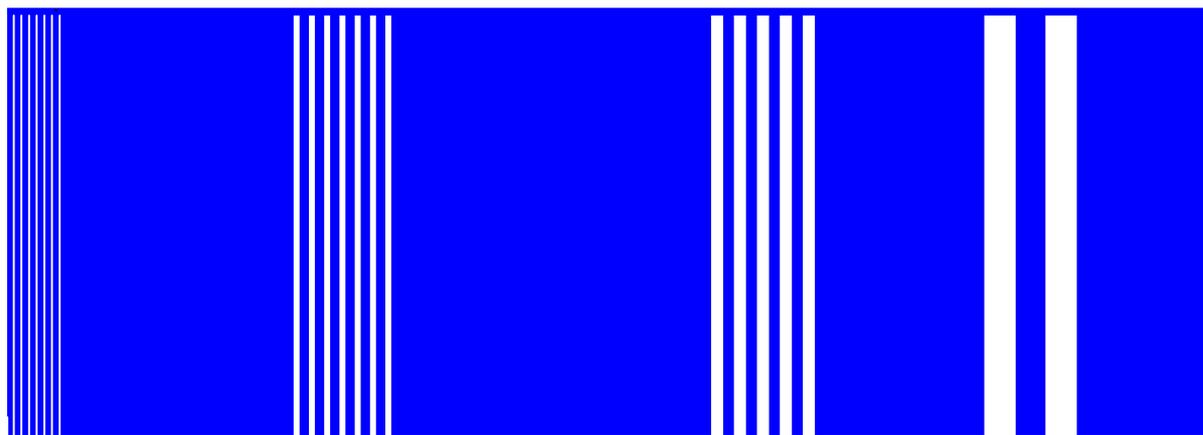
Figure 13.

In the Figure it is possible to see that line groups increment their thickness from left to right. Furthermore, even that the lines have always the same thickness within the group, separations among them are not always the same. The detection of these differences reveals how sensible are our eyes. The eye detects whether spatial frequencies are equal or not, and discriminate among them. It is also clear that such discrimination is related to the distance between the eye and the net.
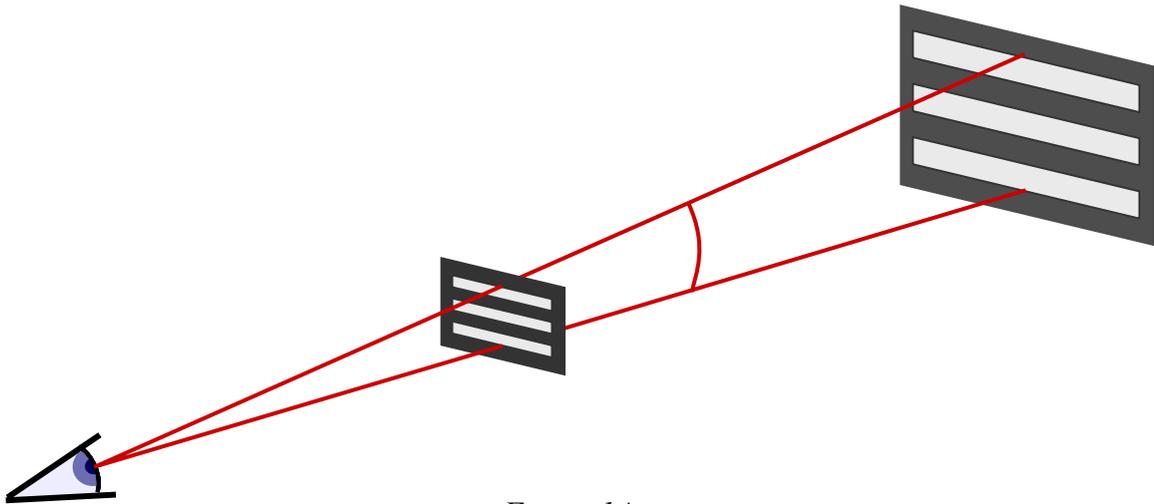
Figure 14.

In Figure 14 it is clearly seen that at short distances nets of higher spatial frequency can be discriminated as in case of letters or texts with letters as in Figure 15. In Figure 16 graphs for human visual discrimination are drawn. The blue on the left shows the discrimination curve for a distance of 40 cm from the object. The red on the right is for a distance of 3 m. The blue one starts discrimination of nets with a wavelength of little less than 0.1 cm, that is 1 mm and reaches its maximum about 2 cm. The red one starts discrimination with wavelengths of 2 cm and reaches the maximum near 20 cm. This shows that spatial frequency discrimination varies with distance, and it is a fact that, for example, the effect called orange peel, needs a certain minimum distance to be perceived.

ABCDEFGHI
BCDEFGHIJ
CDEFGHIJK
DEFGHIJKL
EFGHIJKLM
FGHIJKLMN

ABCDEFGHIJKLMNOPQRSTUVWXYZ
BCDEFGHIJKLMNOPQRSTUVWXYZA
CDEFGHIJKLMNOPQRSTUVWXYZAB
DEFGHIJKLMNOPQRSTUVWXYZABC
EFGHIJKLMNOPQRSTUVWXYZABCD
FGHIJKLMNOPQRSTUVWXYZABCDE
GHIJKLMNOPQRSTUVWXYZABCDEF
HIJKLMNOPQRSTUVWXYZABCDEFG
IJKLMNOPQRSTUVWXYZABCDEFGH
JKLMNOPQRSTUVWXYZABCDEFGHI
IJKLMNOPQRSTUVWXYZABCDEFGH
HIJKLMNOPQRSTUVWXYZABCDEFG
GHIJKLMNOPQRSTUVWXYZABCDEF
FGHIJKLMNOPQRSTUVWXYZABCDE
EFGHIJKLMNOPQRSTUVWXYZABCD
DEFGHIJKLMNOPQRSTUVWXYZABC
CDEFGHIJKLMNOPQRSTUVWXYZAB
BCDEFGHIJKLMNOPQRSTUVWXYZA
ABCDEFGHIJKLMNOPQRSTUVWXYZ

(a)   (b)

Figure 15.

As one can see in Figure 15 there are diagonal orientations between (a) and (b).
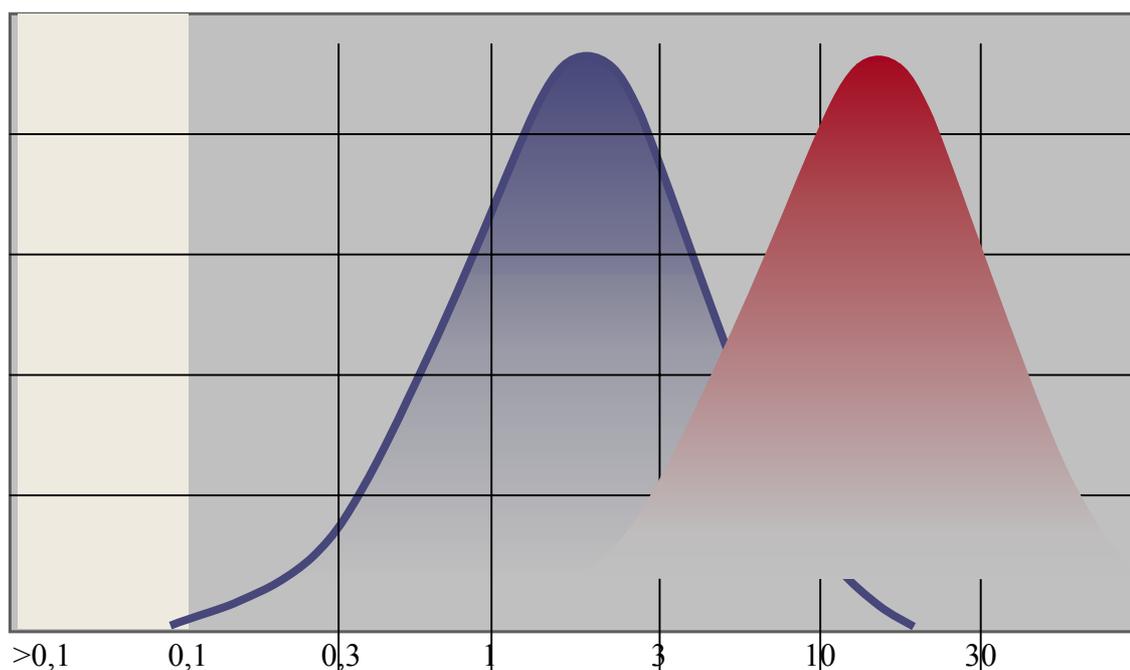
Figure 16.

6. IMAGE VERSUS SURFACE

The clue to understand the appearance phenomena is based on the point of view (and save the redundancy) from where the observation is made, and the way the appearance of the observed surface is perceived. One can set the focus on *the reflected image* or can put attention to the *surface finishing*, and this option is made voluntarily without any effort, but implies entirely different approaches.

When one observes the reflected image, attributes such as *gloss*, *haze* and *definition of image (DOI)* appear. If, otherwise, one pays attention to how is the surface, it is possible to detect the *spatial frequencies*, *rugosity*, *orange peel*, *periodicity*, or *waveness*.

When the focus is on the reflected image one observes how lines are reflected, if they are defined or distorted. To evaluate these characteristics photometric methods are used, tough, in some cases, instruments that try to relate mechanical rugosity of the surface with high spatial frequencies, with wavelengths lower than 0.1 mm by optical methods using the reflection of coherent light.

When a sandpaper of 700 is used to frost a glossy paint surface, gloss disappear, turning matte as consequence of the disappearance of the smooth surface replaced by an irregular surface with valleys and peaks. If the frost is random, then the appearance will be just matte, but if not, structures or drawings can be detected that, if become visually significant, can be treated as *textures*. All liquids have a glossy surface as all fine powders have a matte surface if particles are 2 or 3 times the light wavelength (about 1 μm or 0.001 mm).

When surface phenomena have some periodic structure, their study can use a mathematical tool known as *Fourier analysis*, which employs mathematical series of sinus which can be also treated as net composition of a function called *Fourier transform*. So in the frequency analysis can be related to implicit waves in a graph of two surfaces profile, as can be seen in Figure 17.

It is evident in Figure 17a that frequencies are low, while in 17b are much higher. *Autocorrelation* function is mathematically related with the power spectrum; thus it is possible to establish other methodologies to study these structures.

In Figure 18a the power spectrum (also called Wiener spectrum) is shown through the harmonic analysis of data plotted in Figure 17 using the amplitude variation of the spatial frequency components. In Figure 18b is possible to see that is opposed or reciprocal to the autocorrelated functions. Textures of high frequency have a plane spectrum at very high frequencies. This indicates that measurements enclose fluctuations that vary often comparing with the other graph when variations take place more at random.
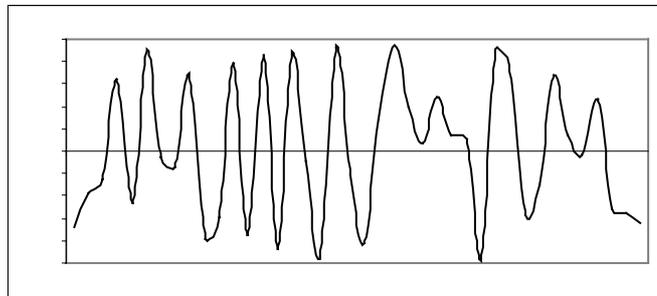
(a)
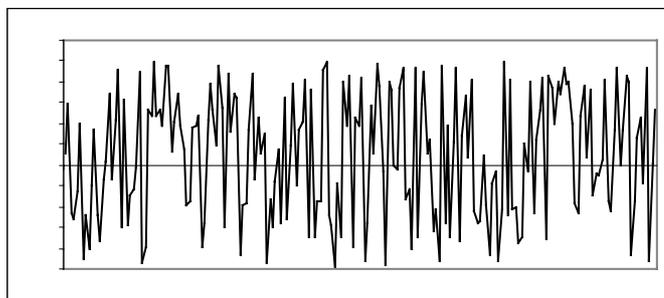
(b)
Figure 17.
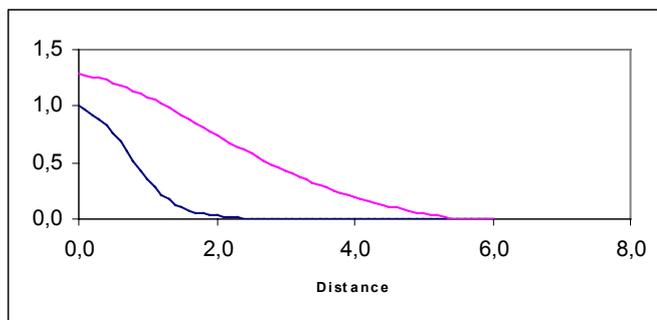
(a) Autocorrelation
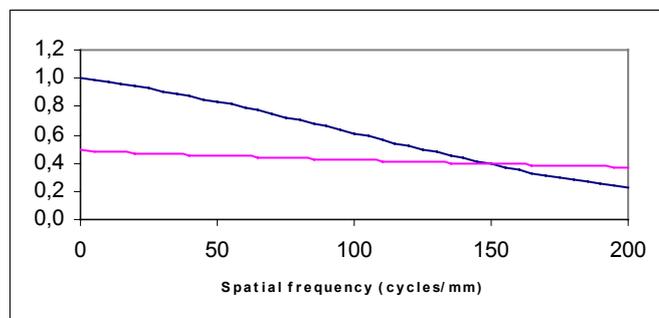
(b) Power spectrum
Figure 18.

Existence of high peaks in the frequency spectrum gives the main direction of texture figures. The peaks place in spectrum indicates the fundamental spatial period of texture patterns, and taking away the periodic components, the non-periodic elements are obtained, which can, then, be described by statistical methods.

Though correlation function and spectrum power are closely related among them and can be calculated through the other, they have different roles. *Autocorrelation is related to physical causes, while power spectrum is important to evaluate the visual impact*.

7. AGAIN ORANGE PEEL

Let us return to the *orange peel* effect. It is evident that we can describe it as periodical phenomena which can be analysed as a frequency spectrum. The problem is: Which frequencies?

Orange peel can be defined as a product of a high glossy surface where is also a waving pattern or periodic waving on the surface defined by clear and dark zones. Their wavelength varies from 1 to 10 mm, though the effect is visible when wavelength is higher than the lower limit.

Waviness or wave periodicity of surface can be seen in the drawing of Figure 19 and its observer perception is product of the simultaneous perception of the multiple reflections produced and indicated by the arrows in the graph for incident and reflected light. The photograph shows what is seen from just one direction. It is the combination of reflections with different angles, the observer head movement, eyes and the binocularity together which produce this complex perception of the whole appearance.
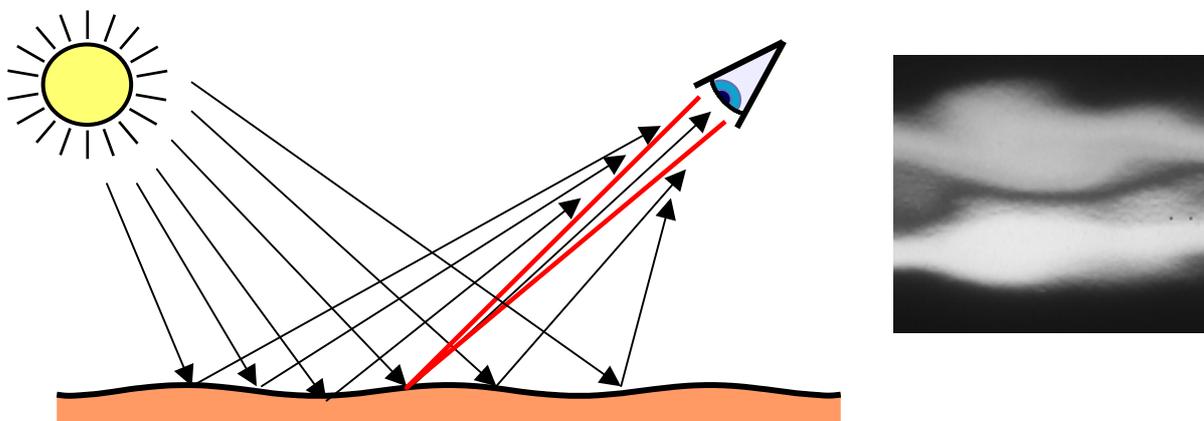
Figure 19.

8. TEXTURE: A COMPLEX PHENOMENON

Orange peel is, without doubts, a kind of texture, but these modes of appearance are much more complex, though the possible universe in paints is limited. It is enough to mention textiles to have an idea of all possible varieties on this subject.

A texture in paints can be of such nature as those found in textured or hammered oven paints, whose characteristics can be better described with the statistic analysis of the surface variations.

From an optical point of view, a surface can be described as *rough* or *smooth*, *fine* or *draft*, *matte* or *glossy*, *regular* or *uniform*. Qualifying antonyms that have a clear visual and cognitive meaning.

Instead, if one describes the surface from a physical or mechanical point of view, one can say that surface is structural, statistic, spectral or fractal. With a less explicit visual significance which, without doubts, requires to be quantitatively explicated.

9. CONCLUSIONS

Visual appearance is a complicated subject and is not completely solved. Different physical alternatives are being used, but people need to know what correlates with different measurements and what they see.

Numbers and evaluations do not always agree. Sometimes a better understanding of the physical process involved is needed.

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Verification of CIEDE2000 using industrial data

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ABSTRACT

CIEDE2000 colour difference formula was recommended by CIE in 2000 for industrial colour difference evaluation. A new set of paint samples was prepared and was assessed by a panel of observers from two companies and one university. The results were used to reveal observer uncertainty, to test different colour difference formulae and to set each formula's colour tolerance. The results show that CIEDE2000 slightly outperformed the other formulae.

1. INTRODUCTION

A new colour difference formula, CIEDE2000, was recommended by CIE in 2000 for industrial applications (Luo, Cui and Rigg 2001, CIE 2001). The formula was developed through an international collaboration between colour scientists from different countries. The formula is based upon CIELAB (CIE 1986) with five corrections, which include a lightness, a chroma and a hue weighting function, and an interactive term between chroma and hue differences for improving the performance for blue colours and a scaling factor for CIELAB $a*$ scale for improving the performance for grey colours. It outperformed the other advanced formulae such as CMC (Clarke, McDonald and Rigg 1984), BFD (Luo and Rigg 1987), CIE94 (CIE 1993) using four independent experimental data sets.

This paper describes a new set of experimental data based upon paint samples using the acceptability (pass/fail) method to judge colour differences. Two phases of experiments were conducted. Phase 1 carried out at the University of Derby, including thirty-eight pairs of samples surrounding a grey colour centre. Phase 2 used 60 pairs of samples surrounding 10 colour centres. These pairs were assessed by a panel of 10 professional assessors from two companies. The results were used to investigate the performances of CIEDE2000 and the other advanced formulae in predicting colour differences having a large range.

2. EXPERIMENTAL

2.1 Sample preparation

The paint samples used in the experiment were prepared by the Cowell, a company also involved in the later visual assessments. The experiment was divided into two phases. Phase 1 investigates only a grey colour centre having the CIELAB coordinates of 51.0, 0.2 and 1.2 for $L*$, $a*$ and $b*$ respectively. Each sample had a size of 5 by 10 cm and was mounted onto a white card. In total, 38 pairs of samples were selected. Figure 1 shows the sample pair distribution surrounding the colour centre in $\Delta a* \Delta b*$ (left) and $\Delta L* \Delta C*$ (right) diagrams. It

can be seen that these pairs were chosen to give a good coverage of almost all directions. Phase 2 experiment used 60 colour difference pairs covering a wide range of colour regions as shown in Figures 2a and 2b for *a*b** and *L*C** diagrams respectively. Each sample was measured by a GretagMacbeth CE7000A spectrophotometer with a large aperture and an exclusion of specular and UV component. The spectro results were then converted to CIELAB values under illuminant D65 and 1964 standard colorimetric observer.

(a)   (b)
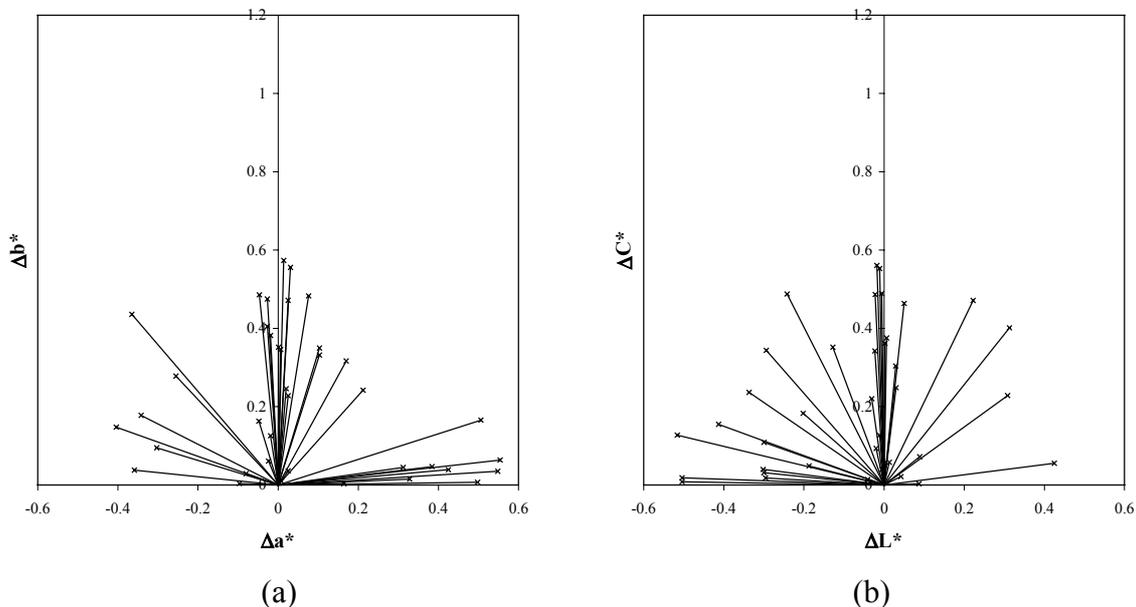
Figure 1. The sample pair distribution for phase 1 experiment in a) Δa* Δb* and b) ΔL* ΔC* diagrams.

(a)   (b)

Figure 2. Sample pair distribution for phase 2 experiment in a) a*b* and b) L*C* diagrams.

2.2 Visual assessment

These pairs were assessed by 10 normal colour vision observers at the University of Derby. Each observer assessed each pair twice. Phase 2 was conducted at two companies with five professional assessors in each lab. Each observer did experiment twice. The instruction shown below is given to observers before each session.

> *Imagine that you just painted half of the wall and you run out of the paint. You went back to buy another tin of that paint. When you paint the wall, you are asked to judge whether you "accept" or "reject" the match between each half of the wall.*

Three GretagMacbeth SpectraLight viewing cabinets were used in each site. It includes a filtered tungsten light source, an accurate D65 simulator with an A grade in visual range (Xu, Luo and Rigg 2003).

2.3 Measure of fit: wrong decision

The data accumulated here described in terms of acceptability percentage, in which a batch sample is judged as pass or fail against a standard in percentage. The acceptability data is described in terms of acceptance % (A%) for a pair, e.g. a 30 A% means that 30% of observers accept the sample as a good match to the standard.

For investigating observer uncertainty, "wrong decision" measure was used (McLaren 1970). For investigating observer accuracy, each individual's results in terms of pass or fail against the panel results in terms of %A were compared. If an individual result is a "pass" against a panel result of 35% which is less than 50% (a "fail"), both results thus disagree with each other for this pair. Hence, it is counted as a wrong decision. The same principle applies to all pairs. Finally, the performance is expressed by WD%, which is the number of wrong decision pairs divided by the total number of sample pairs. For a perfect agreement, WD% should equal to zero. For examining observer repeatability, the WD% measure is also used to represent number of wrong decision made by the two repetitions from a single observer.

For comparing colour difference equations' performance, WD% measure is again used. Two examples are given in Figure 3 by plotting A% of the grey colour centre in phase 1 against the ΔE values calculated by a) CIELAB (2:1) and b) CIEDE2000 (2:1). Each of Figure 3 is divided into 4 regions (Q1 to Q4) by a horizontal line at 50 A% and a vertical line (ΔE_t). A trend can be found that a decrease of A% values with an increase of ΔE values. The wrong decision data is determined by adding the numbers in Q1 and Q3, i.e. the data in Q1 exhibiting small visual differences but large ΔE values of a colour difference equation. The data in Q3 are opposite to those in Q1. When calculating WD%, the line of ΔE_t is varied from small to large colour differences. Each change will calculate a new WD%. Finally, the minimum WD% value corresponds to a particular ΔE_t value. The WD% in Figure 3a and 3b are 26% and 18% respectively, i.e. 10 and 7 data points in Q1 and Q3 divided by total number of pairs (38) for CIELAB and CIEDE2000 respectively.

(a) (b)
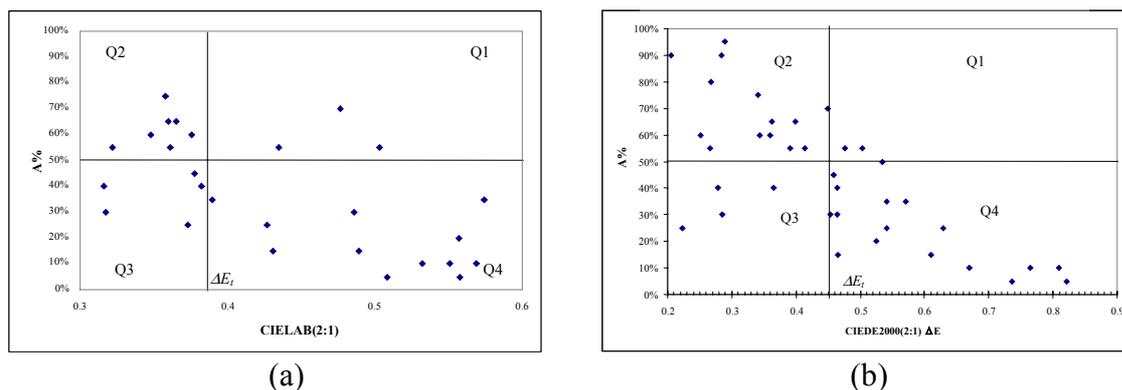
Figure 3. Method for determining the wrong decision for a colour-difference equation to predict an acceptability data set.

3. RESULTS AND DISCUSSION

3.1 Observer uncertainty

Observer uncertainty results were analysed. As mentioned earlier, 10 university observers participated in phase 1 experiment and each observer did assessments twice. This resulted in 20 observations for each of 38 pairs. In phase 2, 5 observers from each company attended the experiment. Each one did assessment twice. The results are summarised in Table 1.

Table 1. Summary of the observer uncertainty in WD% unit.

	Phase 1	Phase 2
Observer repeatability	27 ranged from 16 to 37	32 ranged from 12 to 43
Observer accuracy	28 ranged from 16 to 45	32 ranged from 25 to 38
Between company errors	-	33

Table 1 results showed that there is not much difference between observer accuracy and repeatability. Phase 1 observers performed more accurate and more repeatable than phase 2 observers. However, this could be due to the different coloured sample pairs used in the experiment. Another analysis was carried out to compare the visual results between two companies. It was found that a wrong decision of 33% between two companies. The current finding indicates that observers could have one wrong decision out of 3 judgements.

3.2 Testing different colour difference formulae

The visual results obtained from two phases were used to test four colour difference formulae: CIEDE2000, CMC, CIE94 and CIELAB. Their performances are given in Tables 2 and 3 for phases 1 and 2 results respectively. For each formula, two lightness parametric factors were used, 1 and 2.

Table 2. Performance (WD%) of formulae for phase 1 results (38 pairs).

		CIEDE2000	CIELAB	CIE94	CMC
$k_L=1$	Tolerance ΔE_t	0.45	0.39	0.38	0.52
	WD%	21%	32%	32%	29%
$k_L=2$	Tolerance ΔE_t	0.45	0.37	0.36	0.52
	WD%	18%	26%	26%	24%

Table 3. Performance (WD%) of formulae for phase 2 results (60 pairs).

		CIEDE2000	CIELAB	CIE94	CMC
$k_L=1$	Tolerance ΔE_t	0.38	0.46	0.41	0.42
	WD%	23%	35%	25%	28%
$k_L=2$	Tolerance ΔE_t	0.29	0.37	0.29	0.34
	WD%	43%	48%	38%	43%

(a)　　　　　　　　　　　　(b)

(c)　　　　　　　　　　　　(d)
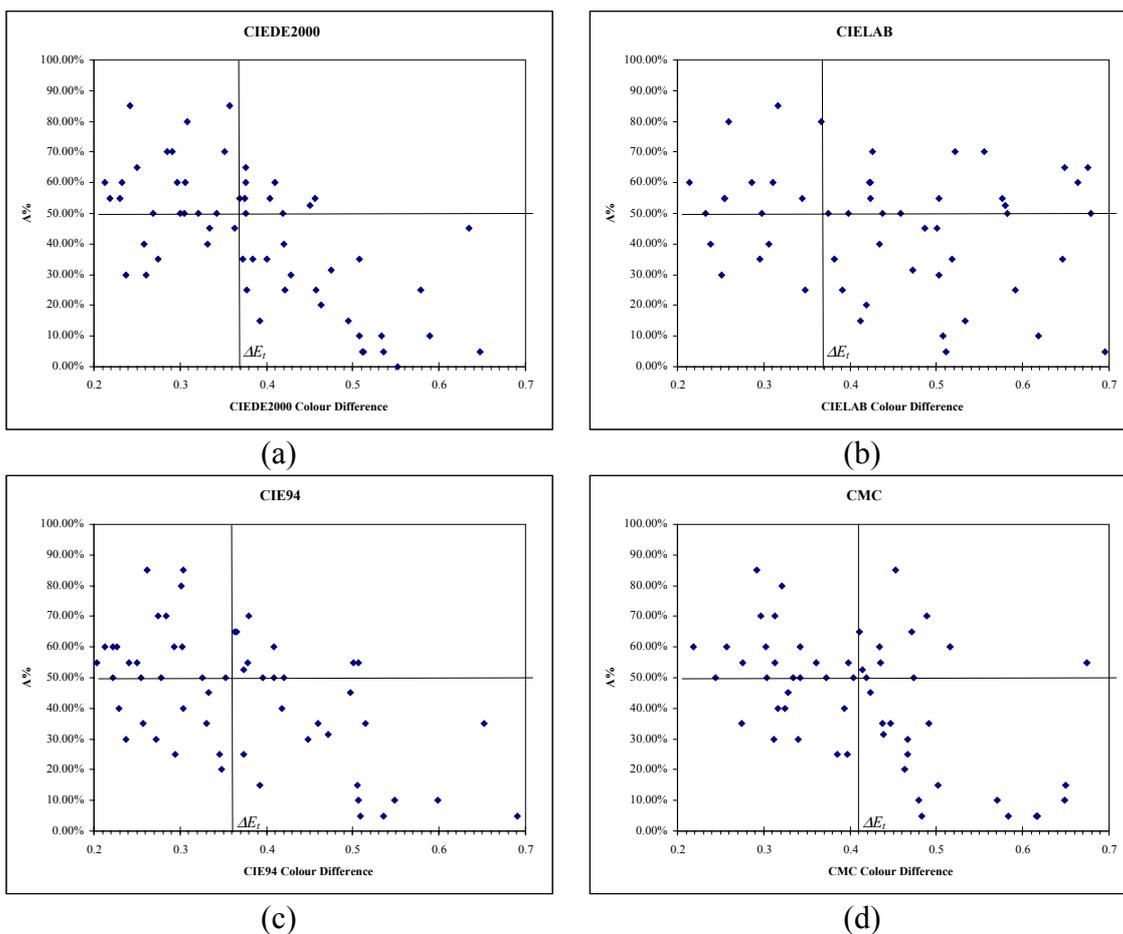
Figure 4. The wrong decision for 4 colour-difference formulae.

Table 2 showed that for each formula with a lightness parametric factor (k_L) set to either 1 or 2, CIEDE2000 performed the best, followed by CMC and CIELAB and CIE94 the worst. For each formula, k_L=2 version performed better than k_L=1 version. However, both versions predict phase 1 results more accurate than the observer uncertainty about 30%. Figure 3 further confirmed the finding that the scatter for CIEDE2000 (3b) is much smaller than that of CIELAB (3a).

Table 3 showed an opposite trend to Table 2, i.e. all formulae with k_L=1 outperformed k_L=2 by a large margin in Table 2. Also, the ΔE_t values between the two tables are quite different. This discrepancy could be caused by the different sample pairs used in each phase and also different groups of observers used (professional and naïve observers). However, again CIEDE2000 slightly outperformed the other formulae. This is further confirmed in Figure 4 by plotting the phase 2 visual results (A%) vs four different formulae with k_L=1. Again, it can be seen that CIEDE2000 formula had a smaller scatter than the others.

4. CONCLUSION

Two phases of experiment were carried out to investigate the performance of CIEDE2000 colour difference formulae. The results imply that pass/fail judgements frequently used in industry are somewhat unreliable with one wrong decision out of three judgements. All colour difference formulae predict visual results more accurate than the observer uncertainty. However, CIEDE2000 consistently performed better than the other formulae.

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Color technology and paint

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ABSTRACT

This paper summarizes current trends in instrumental color styling, color matching and production shading of paint and factors essential to success, with particular emphasis on automotive finishes and research within ASTM and Detroit Color Council committees.

1. INTRODUCTION

The goals of color technologists have gone through cycles starting in the early 1960's. The advent of computers suggested that the visual color matching process could be replaced by total automation. By the mid-seventies, there was a realization that interactive systems with expert colorists were superior to complete automation. Since then advances in color measuring instrumentation, color metrics, expert systems, and visualization technology have reversed the trend back towards that hope of "push-button" systems. We are not there yet, but it no longer seems to be that impossible dream. To successfully approach that dream, we must pursue the "total instrumental color system" (Rodrigues 1979), exploiting the technological advances of the last twenty years, implementing them at all phases of the color matching process, bringing cohesiveness to each successive step: color styling, color formula development, production color control, and color at the customer interface.

Color matching of automotive gonioapparent paints has its own special requirements. These finishes have a binder matrix with transparent pigments surrounding flake pigments which act as tiny mirrors, providing very angle-dependent reflection. Aluminum flakes were introduced in the mid-1930's but were highly scattering. These evolved by the 1980's to highly polished, well-shaped flakes, which together with base-coat, clear-coat finishes provided the glamorous colors we see on today's cars. Aluminum flake containing finishes exhibit mainly a lightness change with viewing angle, being brightest at angles near-specular and decreasing as the aspecular angle increases. This "flop" is attractive because it accentuates the contours of a car. Pearlescent flakes use light interference to also provide hue and chroma flop. While these colors must be matched at all angles of illumination and view, practicality mandates determination of the least number of angles of measurement providing sufficient information for a successful match discussed in section 5.1 below.

Measurements taken at these optimized angles must be expressed in terms as seen by the eye. Most research on color difference equations has addressed only non-flake containing colors. Adaptation of these metrics to automotive color is discussed in section 5.2 below.

All finishes require matching of both color and appearance. A color standard and a batch could measure as a match when measured on an integrating sphere spectrophotometer. However, if they differ in gloss, haze or DOI, they may not pass as a visual match. Flake size, surface smoothness and orientation also provide sparkle and texture, adding to the complexity of matching gonioapparent finishes. Two gonioapparent finishes could measure as a match using a multi-angle spectrophotometer but not pass visual acceptability if they differ in these appearance characteristics. Use of identical flake in standard and batch may not provide the same flop, sparkle or texture if rheology or solids content of the two paints differ. These

factors affect the orientation of the flake as the paint dries, resulting in a different apparent texture and sparkle. This is a problem when a car color has to be matched in both high solids solvent borne paints and in low solids waterborne paints. Little has been published on flake appearance matching. It is largely a visual process, perhaps aided by a microscope.

2. COLOR STYLING

Traditional color styling is expensive. In automotive paints, coatings manufacturers spray panels of potential new color offerings and variations of these. Automotive color stylists choose among these and request tweaking of the colors in particular color directions. Once the preferred colors are chosen, entire vehicles are sprayed to make the final selection. Incompatibilities between the color and the body design may not be anticipated until this stage. Many years ago, when we offered a projection-based color styling tool (Rodrigues 1979), the stylists did not accept it. Today, television and movie graphics have trained us to better relate to simulations. Several companies now offer video systems to view color measured off a color sample, visualizing the object to be painted. E.g., a car can be visualized in its environment, determining combined effectiveness of color and body styling, without the expense of painting the car and shipping it for field viewing in a variety of environments.

The angular range of commercial goniospectrophotometers limits in-depth study of the optimum geometry and number of measurements necessary for realistic and accurate video rendition of goniochromatic color. Some studies (Meyer 2001, Takaghi 2004) suggest 5 angles are sufficient. Meyer has developed software designed specifically for automotive colors. It allows visualization of color on a car by measuring color at the five aspecular angles (15º, 25º, 45º, 75º, 110º) commonly used in the automotive industry. The Graphical User Interface (GUI) allows interactive manipulation of both 5-angle color and gloss of the car. The system also allows display of shapes that are easily "morphed" from a cube to a sphere to a piece of bent sheet metal, changing the angle or curvature of the bend. This would allow the stylist to design the car contours to take advantage of the gonioapparency of the color.

Video technology will limit the number of panel sprayouts, and allow automotive stylists to visualize suppliers' color offerings on their own car models. They could also "tweak" colors to their preferences, giving suppliers quantitative color differences to offset the original color. Color gamut would be constrained only to colors attainable with available pigmentation (Rodrigues 1979). Final color choices will be made with fewer vehicle sprayouts. This technology will reduce costs for coatings manufacturers and for their customers, the automotive manufacturers. It will also streamline the styling process and reduce time in making the final color choices.

3. COLOR DEVELOPMENT

Two significant publications in 1931 opened the door to instrumental color matching. Kubelka-Munk light scattering theory showed us how we could relate color to the absorption and scattering of pigments. The CIE showed us how to reduce spectral measurements to metrics related to the way we see color. In 1949, Duncan provided pigment mixtures equations. These were necessary first steps but it took computers for the repetitive wavelength dependant calculations before instrumental color matching was feasible. Linearization of the Kubelka-Munk equations and iteration to an acceptable match (Allen 1974) made laboratory color matching systems for pigment identification, determination of starting recipes, and adjustment to acceptable matches commonplace. Kubelka-Munk considered only diffuse

fluxes going into and out of the paint. Four flux models (Völz 1964) added collimated fluxes allowing translucency. Linear programming solutions (Belanger 1974) and non-linear modeling to interpolate colorant formula databases (Takaghi 1996) suggested more sophisticated solutions.

Significant developments that have allowed automotive color matching are:

- Increased complexity of light scattering models to address gonioapparency, critical in automotive finishes: Diffuse color matching requires only absorption and scattering coefficients to predict reflectance. Directional characterization of colorants is necessary to allow for color viewed at several aspecular angles, whose optimization is discussed on section 5. Muti-flux models (Mudgett et al. 1971) attempted this but did not allow for characterization of the flake reflectance and apparent cross-section, which is dependent not only on flake size but also its orientation within the film (Marcus et al. 1993, Kettler and Kolb 1997).
- Faster computers and video graphics have allowed user-friendly GUI's and enabled these complex algorithms.
- The improved precision and accuracy of today's spectrophotometers is critical to automotive color measurement and matching. High flop colors have very low reflectance at grazing angles. Detectors in early spectrophotometers could not precisely measure low light signals, thus limiting the angular range for research to optimize angles of measurement. These spectrophotometers did not allow measurements at aspecular angles greater than 75°.
- Robotic spray has allowed standardized application of automotive finishes. Gonioapparent color is very sensitive to spray application. The percent solids when the paint hits the surface affects rheology and rate of drying and hence flake orientation. Color matching requires standardized application conditions so that the shader knows that any color change results from pigment modifications rather than application. Ambient temperature and humidity affect drying rates and hence must also be controlled, particularly in waterborne paints.

These developments, together with portable multi-angle spectrophotometers have enabled Point-of-Sale color matching. This has long been feasible in consumer paints but is now common also in automotive refinish.

4. PRODUCTION SHADING

Shading algorithms for production control are standard on commercial software packages. The holy grail has long been automatic paint making with ingredient dispensing, mixing, and color measurement all under computer control (Falcoff et al. 1985, Auad et al. 1998).

However, tests before paint shipment require checking of not only color but also appearance and a prediction of end-use performance. In automotive OEM, testing must ensure acceptable color, appearance and film properties at the extremes of assembly line application and environmental conditions. Raw material variations can result in paints acceptable in these properties when sprayed under "normal" conditions but still fail on the assembly line. Tests that predict failures before a batch is used on the assembly line save paint supplers the expense and embarrassment of at-line corrections, and eliminate costly assembly line interruptions for the customer (Rupieper et al. 1999).

5. MEASUREMENT OF GONIOAPPARENT COLOR

5.1 Measurement geometry

Integrating sphere and 45/0 geometry have been used traditionally and are appropriate for most paints. Gonioapparent color requires measurements and color matching at multiple angles. ASTM E-2194 standardized on 15º/45º/110º for measurement of metallic colors. The rationale for these preferred angles has been published (Alman 1987, Rodrigues 1990). E-2194 allows for deviations in certain cases. It allows near-specular angles up to 25º when less sensitivity to application is desired. It recognizes that flop angles as low as 70º work in most cases but cautions that these occasionally may not agree with visual assessments, typically made at greater angles. It also provides a ray-tracing procedure to determine the effective aspecular angle and sets tolerances for the percentage of rays that may deviate from the expected angle.

E-2194 is specific to paints containing metal flake. Absolute color of interference flake colors is known to be dependent not only on aspecular angle but also on angle of illumination. Most studies were done on colors containing a high concentration of interference flake, well beyond what would be used in realistic automotive colors. Quality control requires measurement of color difference versus a standard rather than absolute color. We conducted a preliminary experiment within ASTM E-12.12 to determine the importance of incident angle versus aspecular angle in color difference measurement of realistic automotive colors. Bronze and violet automotive colors were chosen and the interference pearl content increased to the limit of acceptability in real automotive colors. In each case a standard panel was weighed, sprayed and replicated. Additionally, panels were made sequentially iterating each ingredient to provide color differences of 2 – 3 CIELAB units. Duplicate panels were sprayed to also determine variation due to application. Measurements were made at aspecular angles of 15º, 25º, 45º, 75º and 110º, each at incident angles of 15º, 30º, and 45º. Color differences (ΔL^*, ΔC^*, ΔH^*) were calculated versus the standard. ANOVA analysis (Table 1) showed that the greatest variation is from the ingredients themselves. This of course allows for ingredient adjustments to match the color. The incident angle variation is extremely small compared to the aspecular angle. In fact even under the controlled conditions of the experiment, application variation was more significant than the incident angle.

Table 1. Summary of ANOVA results.

Main Effect + Interactions	Ingredient	Aspecular Angle	Application	Incident Angle
Mean Sum of Squares Variation % for ΔL^*, ΔC^*, ΔH^*	**101.1**	**48.0**	**6.1**	**3.3**
	Note: Variation can exceed 100% because interactions between effects are included			

These results suggest that current spectrophotometers with a fixed angle of illumination may be used for quality control of real automotive colors. The study is being expanded to:
- more automotive interference colors, including those containing stronger interference effect flakes such as Chromaflair®;
- optimize the choice of incident angles;
- verify whether optimum angles of view are the same as for metallics.

Similar studies are required to optimize angles of illumination and view for absolute color measurement of automotive interference colors.

5.2 Color metrics

Color difference equations adapted to multi-angle measurement are only just emerging. CIE76 was a milestone improvement in relating these measurements to how we see color, but not enough to have instrumental pass/fail judgements required for automatic color matching processes. CMC and CIE94 have helped move in that direction; the jury is still out on whether CIEDE2000 is the next milestone. These studies have all been based on observations of colors not containing flakes. ASTM E-12.12 and the Detroit Color Council (DCC) J1545 committees have started studies on gonioapparent automotive colors.

Most color difference equations today are based on enhancements to the CIE76 equations. ΔL^*, ΔC^*, ΔH^* from CIE76 are divided by weighting functions S_L, S_C, S_H to correct for the non-uniformity of CIE76. CIE94 uses a weighting function for lightness difference of $S_L = 1.0$. However, experience shows that a larger ΔL^* is visually acceptable in lighter gonioapparent colors. We have showed (Rodrigues et al. 2001) that visual lightness difference assessments are better described by:

$$S_L = 0.034 \, L^* \qquad L^* > 29.4$$
$$S_L = 1.00 \qquad L^* < 29.4$$

This linear equation fit the observer data with $R^2 = 0.94$. The data did not justify the curvature of the CMC lightness function or the V-function in CIEDE2000.

This E-12.12 study was extended to a few real automotive metallic colors: beige, silver, gold and teal. Color difference pairs of these colors were shown to twenty observers in a Macbeth Skylight® at 15º, 25º, 45º, 75º and 110º aspecular angles. They were asked whether they would accept the color match if seen on their own car. Logit analysis was used to determine acceptability tolerances at each of these angles. Tolerances averaged over all colors are shown in Table 2. Both equations performed well. However, CIE94 gave more nearly equal tolerances at all aspecular angles.

Table 2. Average acceptability tolerances as a function of aspecular angle.

		15º	25º	45º	75º	110º
CIE94	**Average**	**1.09**	**0.99**	**0.87**	**0.90**	**0.92**
	Coeff of Dev	0.18	0.26	0.21	0.38	0.41
CMC	**Average**	**1.32**	**1.09**	**0.84**	**0.80**	**0.79**
	Coeff of Dev	0.23	0.23	0.13	0.24	0.31

DCC is extending these studies to include larger numbers of current automotive colors including those containing interference flakes. The committee is starting with identification of a preferred experimental procedure, comparing simple pass/fail judgements to comparison to an anchor color difference pair.

Membership includes paint, colorimeter, and light booth suppliers as well as users from car manufacturers. Observers will be drawn from this diverse group of colorists. The committee welcomes any inputs to this work, in terms of experimental process, panel preparation, or analysis of the observer data. The committee will publish these data and also test existing color difference equations to determine effectiveness in assessing the observations.

6. CONCLUSIONS

Research continues to improve instrumentation for color management and control of paints. As we believe we near perfection, there is always a new pigment, paint, or process to challenge us and ensure our continued employment!

ACKNOWLEDGMENTS

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What has made the use of NCS
so widespread in the area of paint?

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ABSTRACT

The NCS-system is purely based on visual perception studies and by this reason extremely well suited for colour communication. The systematic description of colour is a powerful tool that can be used in the analyse, documentation and planning of colour designs. The NCS colour notations are the base for the NCS colour sample collections. They are the professional tools used by colour designers in most countries today. To satisfy their needs 200 new light colours have been introduced. The colour accuracy in these tools and especially for the new 200 light colours is of vital importance both to the industry and for the professional designer.

1. INTRODUCTION

NCS - Natural Color System is scientifically based on more than 100 man-years of research. The research was carried out in a very open-minded environment with researchers coming from architecture, physics, psychology, education and technology —always keeping the focus on the different user groups. NCS is based on perceptual research. The aim behind NCS is to give a simple, and yet accurate way for people to describe and communicate colour. The NCS concept today has the following three components: First, the simple and precise colour description and communication language, the NCS-system. Second, the wide range of professional high quality colour selection tools based on the NCS-system both as colour samples and as software products. And as the third component, the services in NCS Trade to supply the paint industry with big quantities of customised NCS colour tools with the highest accuracy to low cost.

2. COLOUR ANALYSIS

The NCS is a neutral —product independent— colour system describing the colours the way we perceive them. This makes the NCS colour system a valuable tool for many different needs. Professionals can use the colour tools to measure and analyse colours for example in architectural environments. Based on such analyses new colour selections or colour guide-lines can be elaborated and specified.

This is for example a powerful tool in city colour planning to keep alive the colour traditions in historical areas. A given colour selection, for example in a geographical region, can be visually defined and analysed (examples from Brazil, India and Portugal) and can become the base for further colour development and colour planning in that area. Figure 1 shows how NCS can be used to visualize historical colour choices. This example is from Jaipur, the pink city in India (Jutterstöm 2000). Figure 2 shows combination of colours: Chafariz de Dentro —walls, doors, window-frames and railings. This is an example from a colour restoration project in Lisbon (Bissau 2004).
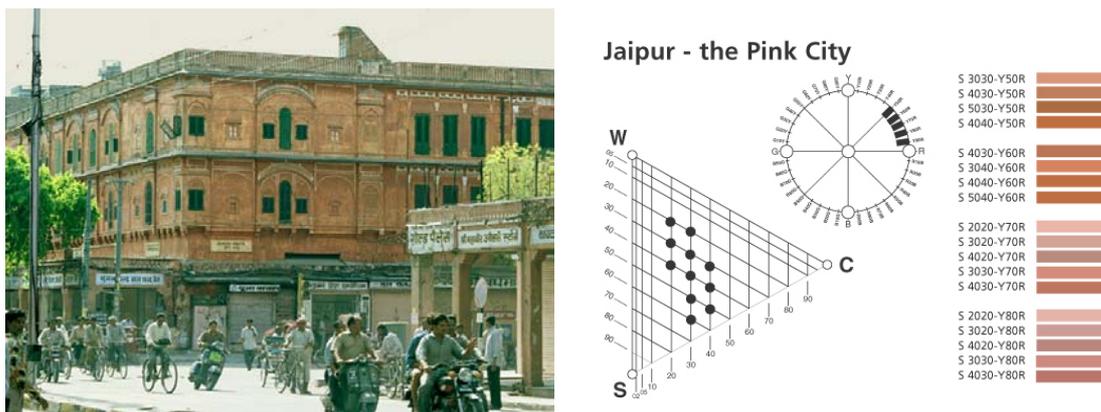
Figure 1. Colours in Jaipur, India.

3. THE NCS PROFESSIONAL COLOUR TOOLS

The NCS colour sample collections are valuable tools both at the local and in the global working area for today's architects. They provide the professional user with a visual example of a colour. The wide network of distributors guarantees availability, support and training. The independency of cultural and trend variations in the NCS colour sample collections provides for global colour communication including regional characteristics.

Based on the NCS-system, the colour samples are evenly distributed over the whole colour space. If the user still needs more accurate notations, visual interpolation between near-by samples can be used. That is possible due to the underlying colour notation system.

A paint manufacturer as well as any other manufacturer of coloured products needs to communicate in a visual way what they can offer as colours to their customers. By use of the NCS colour sample collections they have an instrument for visual colour selection that is recognized as independent by the global architect and design community and could be

Figure 2. Colours in Lisbon, Portugal.

used for any coloured material, not just paint, facilitating the colour and material specification work of their professional customers. Due to the systematic selection of colours, the sampling of the colour space results in a colour collection without the empty areas, "holes" that are often found in paint manufacturers' own colour cards. These "holes" often arise from a production- oriented colour selection based on tinting series.

The "point-of-sales dealer" has a complete system at his hands to help customers to locate the colour closest to the desired customer colour and visually to help them to find their way through the colour space. The NCS Colour Atlas shows the NCS colour space in an accurate and simple way (SIS 2004).

4. COLOUR ACCURACY

Continuity and confidence are two other important features supporting the NCS colour system. The manufacturers of paint and other products must be able to trust the quality of the colour samples and this is equally important for the end users. This will save time and money for both groups. Therefore, the authorized NCS colour samples are subject to a very strict and publicly available quality control, i.e. the NCS Quality Management, created in 1995 together with global paint industries. The highest available quality is the NCS Calibrated Matching Standards guaranteeing a maximum of 0.5 $\Delta E_{CMC(1:1)}$ from the primary standard.

5. NEW NCS STANDARD COLOURS

In 2004, 200 new standard colours were released in the whitish low chromatic area. This extension of the NCS colour sample collections was an answer to the need among architects and designers to have more physical samples with small steps in-between, in the near white area of the colour space, to be able to do more fine-tuned colour design. The use of light colours in colour design is often required due to both governmental restrictions and the user preferences. The new light colours give better lightning as well as better economy due to higher light reflectance. The strength of the NCS-system is its ability to extend the colour sample collections with in-between colours and then using the system to select, notate and define the tolerances of the new colours.

6. NEW NCS TOLERANCE AREAS

For the new colours, tight tolerance areas are necessary due to the small differences between these and the earlier colour samples. The tolerance areas were selected based on the desired perceived difference to existing colours and to allow for reliable reproduction by the paint industry. The industry and professional users also need high quality physical standards for the new colours that must be reproducible inside the new tolerance areas.
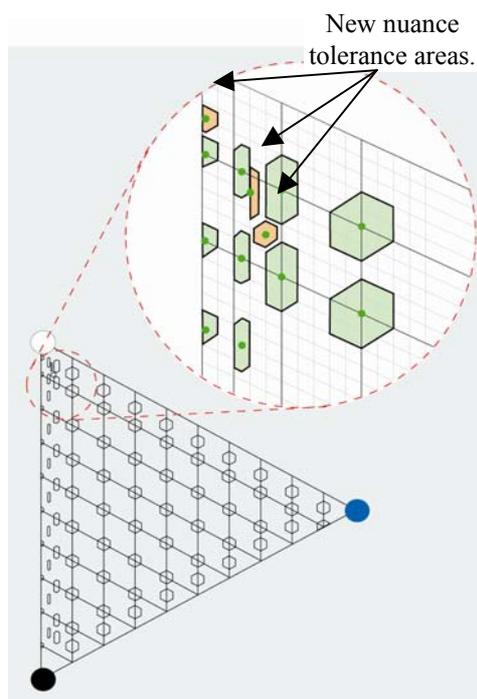
Figure 3. Nuance tolerance for some of the NCS 200 new colours.
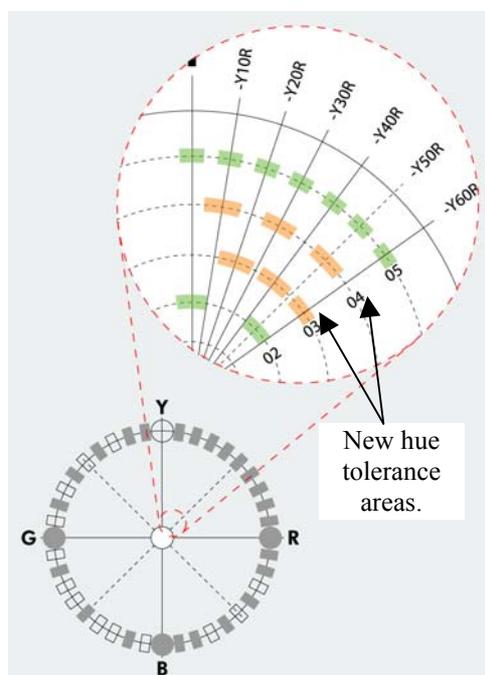
Figure 4. Hue tolerance for some of the NCS 200 new colours.

NCS tolerance areas are divided into two levels, nominal tolerances and production tolerances:

NCS nominal tolerances are based on the perceptive research behind NCS. It states that for a colour sample to be visually representative for its colour notation, it should be within 2 units in blackness, chromaticness and hue from the nominal notation. For the low chromatic colours narrower tolerances are necessary.

The production tolerance is based on the need from the professional users. That is to get exactly the same colour on each colour sample with the same notation.

The NCS 200 new colours are placed in between the present colours. This sets new demands on the tolerance areas in the light, low chromatic area. In this area, many paint manufacturers' colour collections contain near-by samples that are almost impossible to see a difference between. Many of these colours can be replaced by each other within the normal production tolerance in the paint industry.

To extend the NCS colour sample collections in this area, both visual and industrial tolerances must be taken into consideration. For example, the tolerance area of the new nuance S 0603 will have a common border with the tolerance area of S 0502 (Figure 3). To avoid the possibility of these two notations having exactly the same colour, they are not allowed to have the same hue (Figure 4).

7. NCS COLOUR SAMPLE PRODUCTION

Each year the 1950 standardized NCS-colours are reproduced. The produced colour samples are used both for the NCS original colour tools and for customized NCS colour tools in the NCS Trade project. More than 800 hours are invested in this annual quality control project. The colour samples are divided into different quality levels depending on their future use, each quality level with clearly stated quality goals. The results for the different groups are published after each production round and a comparison over the years shows that a consistent and extremely high quality is being maintained for the best of the users.

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Cesia and paints: An atlas of cesia with painted samples

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ABSTRACT

The name "cesia" has been given to the modes of appearance produced by different spatial distributions of light. The aim of this paper is to present a new atlas of cesia produced with painted samples. The atlas consists of 5 pages with 25 samples each, that is to say, a total of 125 samples. The samples in every page have a different degree of perceived *permeability* to light, from the opaque samples to the transparent ones, passing through samples with different degree of perceived turbidity. Furthermore, in each page, the variation of *darkness* (from very light to very dark) and the variation of *diffusivity* (from matte or translucent to glossy or crystalline) occur.

1. INTRODUCTION AND ANTECEDENTS

The name "cesia" has been given to the modes of appearance produced by different spatial distributions of light (Caivano 1991, 1993, 1994, 1996). From the physical point of view, an object may absorb light, and the non-absorbed portion can be either reflected by the material, or transmitted trough it. Both reflection and transmission may occur regularly (specularly) or diffusely, and any intermediate combination may also appear. Those physical transfers are the stimuli for the visual sensations of cesia: matte appearance, glossy or mirror-like appearance, translucency, and transparency, with different degrees of darkness, and all the intermediate or combined cases. Every color appears in some of these modes of appearance, and vice versa. Now on, the stimulus for color can be produced by *primary sources* (objects that emit light) or by *secondary sources* (objects that reflect or transmit the light coming from another source). Both in a primary or a secondary source we can have a variation of color, but the variations of cesia only occur in secondary sources, that is to say, in objects that produce changes in the spatial distribution of the light that they receive. These changes are mainly due to micro-textural variations on the surface or in the volume of the object. If these textural variations are of a rather small size, then the texture itself is not perceived, but the effect produced on light is, and we see cesias.

The three variables originally proposed for cesia are *permeability*, *absorption*, and *diffusivity*. As the word "absorption" usually refers to a physical process, *darkness* is perhaps better to allude to the resulting visual sensation. Thus, the variables could be termed perceived *permeability* (or its opposite, *opacity*), perceived *darkness* (or its opposite, *lightness*), and perceived *diffusivity* (or its opposite, *regularity*, related to the distinctness of image, not only referred to the sharpness of images produced by reflection but also by transmission).

Paints are one of the most versatile materials to produce these kinds of variations. A paint may cover a surface, working as an opaque coating, and in that case the stimulus for cesia is due to the surface finishing. A rough surface produces a matte effect, while a polished surface produces gloss. But if the paint is more or less transparent, then, in addition to the surface finishing, the internal composition, working in the whole thickness of the layer, is important. In these cases, the stimuli for cesia are of a more complex nature. An atlas of cesia made with

pieces of glass was presented in AIC 1997, Kyoto (Caivano and Doria 1997). The samples in the atlas allow for comparison of different kind of specimens. The samples of glass range from translucent to transparent, matte to mirror, permeable to opaque, and light to dark (Figure 1).
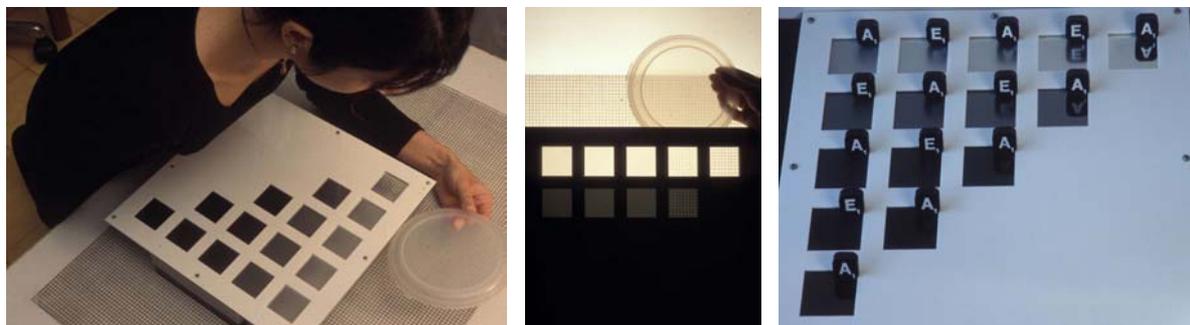
Figure 1. Atlas of cesia made of glass. Left and center: a specimen is being compared against the translucent and transparent samples. Right: the opaque samples, from matte to mirror.

2. THE ATLAS MADE WITH PAINTS

Now we want to present a new atlas of cesia produced with painted samples that is being developed. The atlas consists of 5 pages with 25 samples each, that is to say, a total of 125 samples. The samples in every page have a different degree of perceived *permeability* to light, from the opaque samples (1st page) to the transparent ones (5th page), passing through samples with different degree of perceived turbidity (Figure 2). Furthermore, in each page, the variation of *darkness* and the variation of *diffusivity* occur. For rather opaque objects, *darkness* goes from very light or white to very dark or black, and diffusivity goes from glossy to matte. For rather transparent objects, *darkness* goes from very clear to very dark or black, and diffusivity goes from crystalline to translucent. The notation for the three variables, *permeabilit*y / *darkness* / *diffusivity*, goes from 0 to 1 or 0% to 100%.
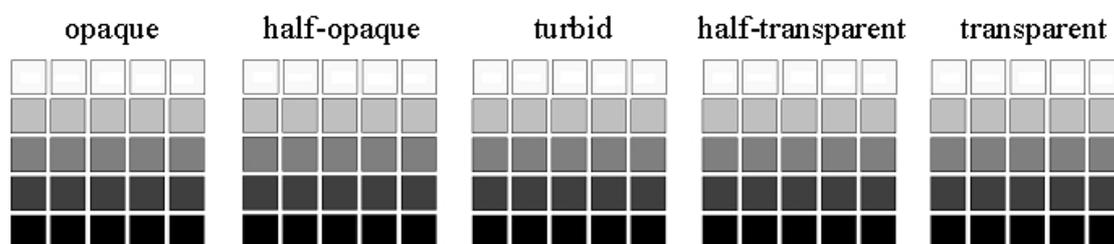
Figure 2. Scheme of development of the atlas, from the opaque samples to the permeable or transparent ones. In vertical, the variation of darkness. The variation of diffusivity (not shown here) occurs in horizontal, in each page.

All the samples are being produced by mixing 9 kinds of paints: alkyd enamel of white color (in matte, satin, and glossy finish), alkyd enamel of black color (also in matte, satin, and glossy finish), and clear alkyd varnish (in matte, satin, and glossy finish). The samples are painted on an opacity display and extended with a bird film applicator on a surface in which a pump has made vacuum (Figure 3).
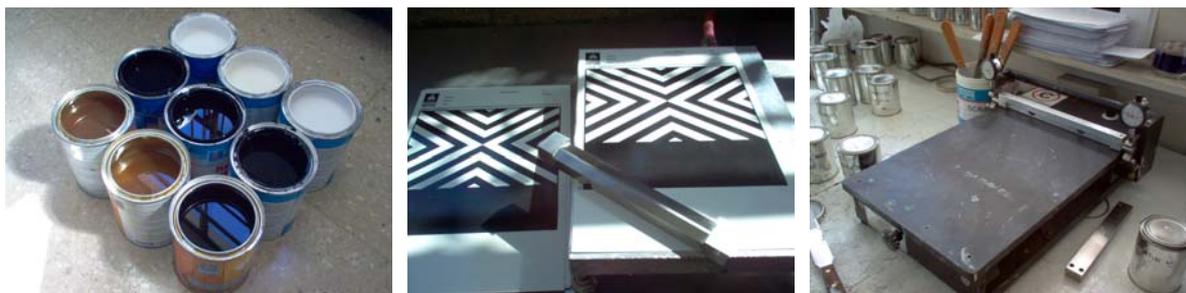
Figure 3. Some of the materials and elements used to produce the samples.

These paints are mixed according to established proportions following arithmetic scales or scales derived from a power function (Stevens' law): *sensation = k . stimulus$^\beta$* (Stevens 1975). A hypothesis is made for each kind of scale as to what are the β exponents that better work in each case. Then, the mixtures of paints are produced following the corresponding proportions and the samples are painted. And finally, when a scale of 5 steps has been completed, the whole scale is assessed visually to verify the regularity of the intervals and steps. If not approved, a new exponent β is tried and the whole procedure is repeated.

According to our results, scales of darkness follow a power function with β = 0.4, mixing black and white (for the opaque samples). The power function with β = 0.4 also works mixing black and varnish (for the transparent samples), and mixing black, white and varnish (for the intermediate permeabilities). In these intermediate permeabilities, white is used to increase turbidity on the varnish. Scales of diffusivity are made by mixing the glossy paints with the satin paints, and the satin paints with the matte paints to obtain the intermediate degrees. These mixtures give correct results if they are made in a half and half proportion.

Figures 4 to 6 show some of the results achieved at this moment. This work is still in progress, and the final results will allow us to compare the atlas made of pieces of glass in 1997 with the present one made with paints, and speculate about the possibilities of cesia for different kind of materials.
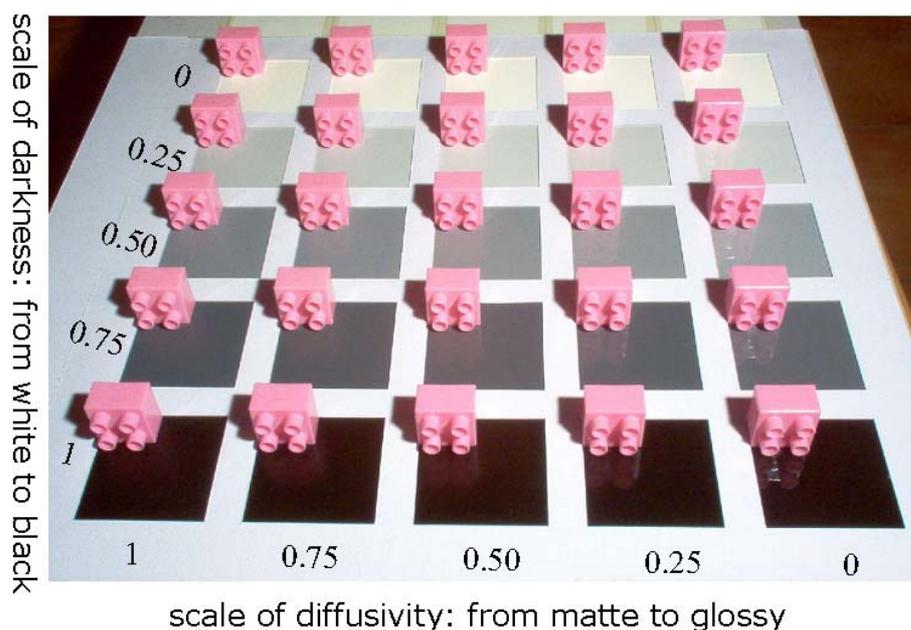
Figure 4. Page of opaque samples, with the variation of darkness and diffusivity. For this photograph, an object has been placed on each sample so as to appreciate the variation of diffusivity (more evident in the dark zone).
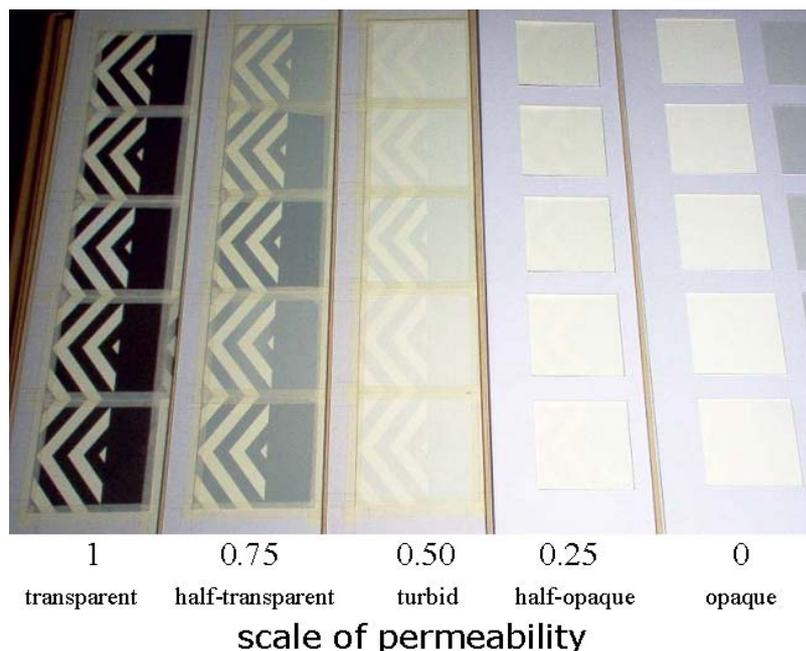
Figure 5. Five steps of permeability. Even when it cannot be appreciated in the photograph, the variation of diffusivity occurs in vertical for each step. With the addition of the variation in darkness, each of these scales originates, in turn, a whole page like the one in Figure 4.

1	0.75	0.50	0.25	0
transparent	half-transparent	turbid	half-opaque	opaque

scale of permeability
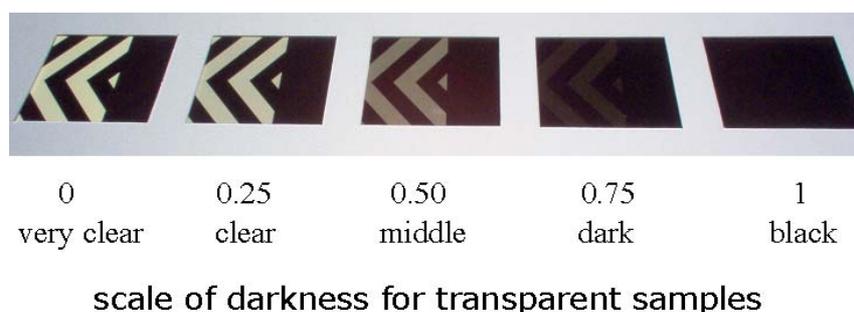
Figure 6. The variation of darkness for a transparent sample (permeability 1), with a certain degree of diffusivity (in this case, diffusivity 0).

0	0.25	0.50	0.75	1
very clear	clear	middle	dark	black

scale of darkness for transparent samples

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Assessing colour differences with different magnitudes

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ABSTRACT

The CIEDE2000 colour difference formula recommended by the CIE in 2000 is mainly used for evaluating small size colour-differences (less than 5 ΔE_{ab}^* units). This study is intended to investigate the performances of this formula together with the others in predicting a newly accumulated experimental data set having a wide range of colour differences. The data included 4 subsets: surface textile samples, and CRT colours with small, medium and large magnitudes. Each subset had 62 pairs surrounding 5 colour centers.

1. INTRODUCTION

Colour-difference formulae have been widely used in the surface colour industries such as textiles, coatings, plastics. They have been devised mainly based upon the colour differences of small magnitudes because the majority of the colour differences concern with accurate colour reproduction. For example, the CIEDE2000 colour difference formula (Luo and Rigg 2001) recommended by the CIE in 2000 stated that it should be used for evaluating colour differences less than 5 ΔE_{ab}^* units. However, in many applications such as product design and graphic arts, the colour differences concerned cover a large range. In this study, new experiments were carried out to accumulate data covering a wide range of colour-differences. The data were used to investigate the performance of various colour difference formulae.

2. EXPERIMENTAL

Experiments were conducted using two different media: physical textile samples and colour stimuli presented on a CRT display. Sixty-two pairs with an average of 5.4 ΔE_{ab}^* units of textile samples were first assessed against a grey background having $L^* = 50$ by a panel of 8 observers and each repeated the same experiment twice using grey scale method. All pairs were mainly exhibited chromatic differences, i.e. ΔL^* values were relatively small. All observers had normal vision according the Ishihara test. Each sample had about 10° viewing field subtended to observers' eyes and the experiment was conducted under a D65 simulator. Each observer was asked to provide the visual results in terms of grade value of the reference grey scale. Finally, the grade values were transformed to a linear scale in terms of visual colour difference (ΔV). The average ΔV for each pair was used for subsequent data analysis. The details of the grey scale method can be found in the article by Luo and Rigg (1986).

The physical samples were originally prepared by Xin, Lam and Luo (2001) to surround four chromatic colour centres and a grey centre (see Table 1). The selection of colour centers was based upon the study of Hegie, Wardman and Luo (1996), which investigated the largest disagreement between three advanced colour-difference formulae CMC (Clarke, McDonald and Rigg 1984), CIE94 (CIE 1995) and BFD (Luo and Rigg 1987). The experiment was then repeated by reproducing these colour stimuli on a Barco monitor. All simulated pairs were

assessed by the same group of observers. Two additional sets of CRT stimuli were also generated with 150% and 200% colour difference enlargements of the original pairs. This was achieved by adjusting the colour co-ordinates of the "batch" of a pair with no change of the "standard". The ΔL^*, ΔC^* and ΔH^* in the original pair were multiplied by a factor of 1.5 or 2.0 in order to obtain the colour co-ordinates of the "batch" sample. The average ΔE^*_{ab} values of three subsets of CRT stimuli are 5.4, 8.0 and 10.7 units.

Table 1. CIELAB values of five colour centres.

Colour centre	L*	a*	b*	C*	h°
Orange	48.9	10.3	16.9	20.0	59.6
Yellow	76.3	-1.8	19.3	19.6	95.3
Green	29.6	-13.4	-0.1	13.6	180.6
Blue	26.7	8.4	-20.1	22.1	292.8
Grey	48.8	-1.7	-0.3	3.8	177.3

3. DATA ANALYSIS

The PF/3 measure (Luo and Rigg 1987) was used here to indicate the degree of disagreement between two sets of data in terms of percentage errors. It is a statistical measure including three different measures of fit, γ, V_{AB} and CV. For the prefect agreement, PF/3 should be 0. A PF/3 value of 20 means a 20% disagreement between the two data sets compared.

Observer uncertainty was investigated in terms of observer accuracy and repeatability. It was found the PF/3 values of 42 and 38 for accuracy (individual against mean) and repeatability (individual's two repeated assessments) respectively.

For revealing the media effect, the ΔV values of physical pairs were plotted against those of CRT stimuli. It was found a good agreement between them, i.e. a small scatter with strong positive correlation. However, there is a systematic trend that the perceived colour differences of physical samples are 20% larger than those of CRT.

In studying the magnitude effect, all sample pairs were divided into three categories according to the magnitudes of CIELAB ΔE^*_{ab} values. They are named CRT-small (ΔE^*_{ab}<5), CRT-medium (5≤ΔE^*_{ab}≤8) and CRT-large (ΔE^*_{ab}>8). These were used to test the six chosen formulae: CIELAB, CMC, BFD, CIE94, CIEDE2000, and Attridge and Pointer (AP) (2000). Table 2 summaries their performances using the three subsets and the combined set designated as "All". Note that Attridge and Pointer derived a power function based upon each formula to fit their own experimental data, which also included a large range of colour differences. The best performed formula is *1.7256ΔE_{94}*[0.6471].

When comparing between a formula's predictions and visual results, a slope was calculated to adjust the former to have the same scale as the latter. It was found that all equations had the highest and the lowest slope for the CRT-large and CRT-small subsets, respectively. The mean ratios from all formulae are about 1.00:1.10:1.20 corresponding to small:medium:large colour differences. This indicates that all formulae over-predicted medium and large colour differences by about 10% and 20% respectively.

Comparing the performances between different formulae, all formulae had the lightness parametric factor of one. As mentioned earlier, all pairs had mainly chromatic difference so that there is no need to test formulae by varying lightness parametric factor. The results for the combined set ("All") showed that CIEDE2000, BFD, CIE94 and AP gave similar performance and outperformed CMC and CIELAB. CIEDE2000 gave the most accurate prediction to the

small and medium magnitude subsets. Comparing the performance of a particular colour-difference formula in different magnitudes, CMC performs better in the small colour-difference; in contrast, CIELAB, CIE94 and BFD are more accurate in predicting the large subset than the small subset. The AP formula performed quite well, which indicates that a great similarity between the presented data and Attridge and Pointer data. Overall, all formulae performed quite accurate, i.e. their prediction errors ranged from 20 to 25 PF/3 units are much less than observer uncertainty (about 40 PF/3 units).

Finally, a 2nd order polynomial equation, ΔE_N, was fitted to the "all" data set for each colour difference formula, i.e. $\Delta E_N = c_1 \Delta E^2 + c_2 \Delta E$. The results are also given in Table 2. In addition, the visual results (ΔV) are plotted against colour differences calculated from six colour difference formulae and given in Table 2. As shown in Figure 1, the ΔE_N equation for each of the six colour difference formulae forcing the curve to go through the origin was used to fit the whole data set. These plots confirm with those found by Attridge and Pointer that a power function should fit the data well and more scatter in large colour-difference region.

Table 2. Colour difference formulae performance in terms of PF/3.

		CIELAB	CIE94	CMC	BFD	CIEDE2000	AP
CRT-small	$\Delta E_{ab}^* < 5$	31	19	22	23	18	23
CRT-medium	$5 \leq \Delta E_{ab}^* \leq 8$	26	18	22	19	16	19
CRT-large	$\Delta E_{ab}^* > 8$	22	18	24	18	19	19
	All	25	20	24	20	20	20
ΔE_N	All	25	19	20	19	18	20

The results in Table 2 clearly showed that comparing the performances of different formulae to fit the whole data set using the best fitted line and the curve line (ΔE_N), the improvement is quite limited, i.e. within 2 PF/3 units except for CMC (4 units). This implies that although each formula was designed for estimating small magnitude colour differences, they are capable of predicting large magnitude colour differences with reasonably accuracy.

4. CONCLUSION

A new set of experimental data was accumulated including 4 subsets based upon textile samples and CRT colours having different colour difference magnitudes. The results are summarised below:-
- Regarding to media difference, the results showed that physical samples appear to have a 20% larger colour difference than CRT colours.
- All colour difference formulae over-predict larger colour differences.
- All formulae predicted the current data set more accurate than the observer uncertainty.
- CIEDE2000, BFD and CIE94 performed slightly better than CIELAB and CMC.
- The current data agreed well with the Attridge and Pointer data.
- To apply a 2nd order polynomial function has little improvement for each formula to predict the current data set. This implies that all formulae are capable of predicting a wide range of colour differences.
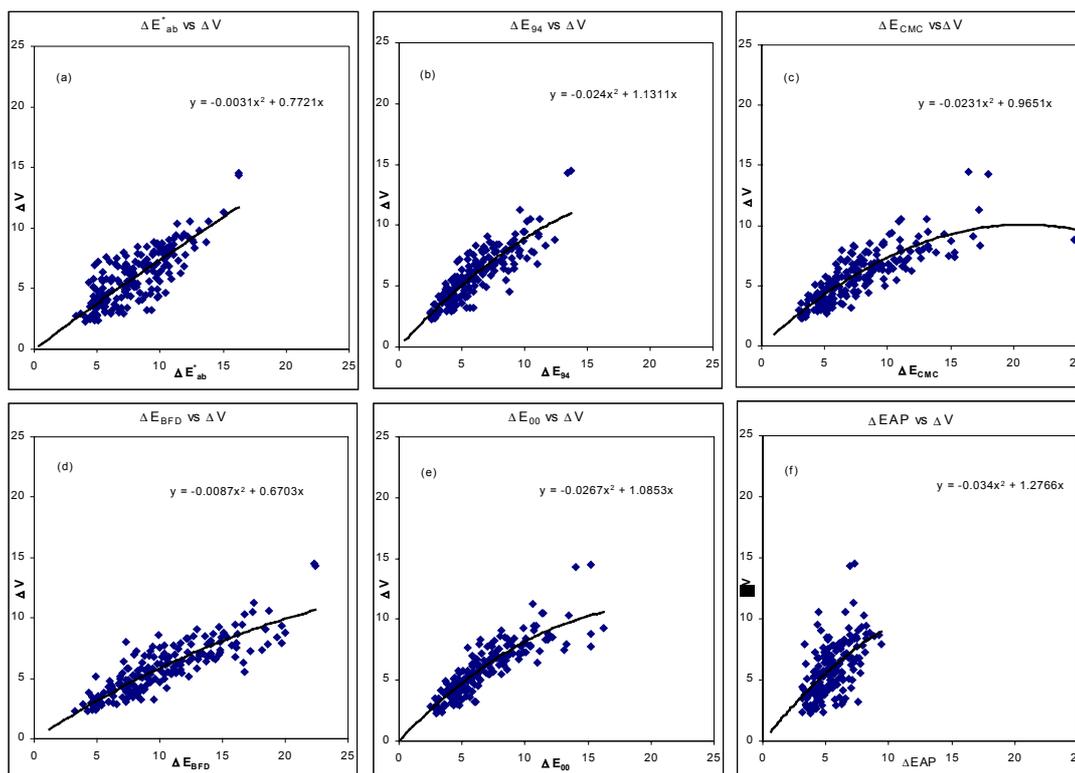
Figure 1. Visual results against colour difference calculated from 5 colour difference formulae.

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Colour appearance of fruit juice affected by vitamin C

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ABSTRACT

The effects of vitamin C on the changes of 25% mao juice quality was studied. Mao juice was extracted from frozen mao and had a pH 3.5 ± 0.1; it contained $17.6\pm0.3^{\circ}$Brix, 17.6 ± 2.2 mg anthocyanins/100 ml juice and polyphenol oxidase (PPO) activity. No vitamin C was found in the juice. Mao juice (25%) was pasteurised at 85°C for 10 min. This condition completely ceased PPO activity and destroyed microorganisms but retained high anthocyanins content (91%). Vitamin C was added to the juice at various levels to yield 10, 25, 50, and 100% of vitamin C daily intake per bottle after pasteurisation. The pasteurised juice was then hot filled in 190-ml tinted glass bottles with 4.5-ml headspace. Changes in pigment concentration, colour and ascorbic acid content were monitored during storage at 30°C. Fortification with vitamin C reduced the half-life values of pigment. The *a** values of all samples decreased over time, indicating a decrease of redness in the juice colour. The preference in redness and in overall colour ranged from "like slightly" to "like moderately" during the storage in every sample. The change of colour appearance in mao juice due to the addition of vitamin C was negligible.

1. INTRODUCTION

The role of a healthy diet is becoming important and is of great interest in the food industry. Consumers tend to choose food products that are high in nutrition. To meet consumers' needs, many food products have added some minerals/vitamins to improve their nutritional value. In fruit juice, vitamin C is always added. However, vitamin C is one of the major factors affecting the stability of anthocyanins in the food system. The addition of vitamin C may affect the colour of fruit juice and this may lead to unacceptability by consumers, as colour is also one of major parameters influencing the quality of fruit juice. Poei-Langston and Wrolstad (1981) observed that addition of ascorbic acid to model system of anthocyanins resulted in loss of pigment stability. Skrede et al. (1992) also reported that ascorbic acid caused a decrease in pigment stability. In this study, mao juice was chosen. Mao (*Antidesma* sp.) is a tropical shrub widely grown in the northeastern part of Thailand. In the juice processing, mao juice was extracted from frozen mao. The purpose of this study was to investigate the effects of vitamin C on colour appearance and colour stability of fruit juice.

2. MATERIALS AND METHODS

Frozen mao was used as raw materials and after crushing, the juice was filtered. The extracted juice, pH 3.5 ± 0.1, containing $17.6\pm0.3^{\circ}$Brix was analysed for anthocyanins content, vitamin C and polyphenoloxidase (PPO) activity. PPO activity was determined according to method of

Duangmal and Owusu-Apenten (1999). Mao nectar (25% juice) was then prepared. Total soluble solid was adjusted to 15°Brix by adding sugar and citric acid. The juice was then pasteurised at 85°C for 10 min in a jacketted kettle. The heated juice was divided into 5 portions. Vitamin C was added to each portion to yield 0, 10, 25, 50, and 100% of vitamin C daily intake per bottle after pasteurisation. The pasteurised juice was then hot filled in 190 ml tinted glass bottles with 4.5 ml headspace and stored at 30°C. For each sample group, two bottles were randomly selected for analysis every week for a period of 24 weeks. The samples were analysed in terms of anthocyanins content and colour analysis. For vitamin C content, analysis was done every 3 weeks.

Anthocyanins content was determined using the pH differential method (Fuleki and Francis 1968). Absorbance was measured at 526 nm with a Shimadzu UV240 spectrophotometer. Anthocyanins content was expressed in terms of relative anthocyanins.

HPLC analysis of total ascorbic acid was carried out using a Linchrocard Lichrospher 100 RP 18 (5 μm), 125 × 4 mm (Merck). Conditions: 0.3 mM K_2HPO_4 in 0.35 v/v *o*-phosphoric acid; isocratic programme for 20 min; elution at 0.5 ml/min; injection volume 50 μl; detection at 248 nm.

CIE L^*, a^*, b^* values were measured with a Minolta CT-310 colorimeter, with illuminant D65 and 10° observer. Chroma $(a^{*2}+b^{*2})^{1/2}$, hue angle (arctan b^*/a^*) and total colour difference, ΔE^*, $(\Delta L^{*2}+\Delta a^{*2}+\Delta b^{*2})^{1/2}$ were calculated.

For visual colour analysis, thirty observers were asked to evaluate the overall colour quality and redness preference of the sample as a fruit drink and to rate it using a 9-hedonic scale from dislike extremely to like extremely.

3. RESULTS AND DISCUSSIONS

It was found that the juice contained 17.6±2.2 mg anthocyanins/100 ml juice and PPO activity. The activity of this crude enzyme was 2,734±446 units/mg protein. It has been reported that fruit juice normally contains PPO. And the degradation of anthocyanins is mainly due to PPO present in juice. Skrede, Wrolstad and Durst (2000) reported this phenomenon in highbush blueberries. Kader et al. (1997) demonstrated that PPO activity plays a dominant role in enzymatic browning of blueberry anthocyanins. Since addition of vitamin C can inhibit PPO activity, this action may retard the pigment degradation before pasteurisation and maintain colour stability of the juice.

Figure 1 shows changes in anthocyanins content in mao juice, reported in the form of anthocyanins retention, over a period of 24 weeks. There appeared to be a higher loss in anthocyanins content when the storage time increased. A plot of *ln* (C/C_o) versus storage time (where C is anthocyanins content after *t* days of storage and C_o is initial anthocyanins content) yielded a straight line. Linear regression analysis showed that degradation of anthocyanins in the juice followed first order reaction kinetics. The rate of anthocyanins degradation constant in juice containing 0, 10, 25, 50, and 100% of vitamin C daily intake per bottle was 8.00×10^{-3}, 8.20×10^{-3}, 9.30×10^{-3}, 1.02×10^{-2}, and 1.09×10^{-2} / day, respectively. The result agreed with those of previous studies reporting first order kinetic for anthocyanins present in blackcurrants nectar (Iversen 1999), and strawberry juice and concentrate (Garzon and Wrolstad 2002).

As expected, the vitamin C promoted anthocyanins degradation. Linear regression analysis provided evidence that ascorbic acid degradation fitted first order reaction kinetics. A similar pattern of vitamin C degradation was also reported in strawberry juice containing ascorbic acid (Garzon and Wrolstad 2002), and also in blackcurrant nectar (Iversen 1999).

The more vitamin C that was added, the higher the anthocyanins degradation. Half-life value of anthocyanins in the juice was about 88 days. The half-life values of anthocyanins in samples containing vitamin C, in the range of 10, 25, 50, and 100%, were markly decreased with the values being 84, 74, 68, and 63 days, respectively. The addition of more vitamin C appeared to lower the stability of anthocyanins. To evaluate whether the changes in pigment would affect the changes in colour appearance of the juice, measurements of CIE L^*, a^*, b^* values and visual colour analysis were carried out.
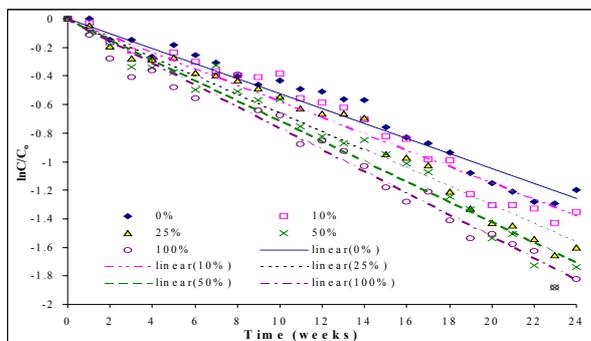
Figure 1. Degradation of anthocyanins in mao juice.
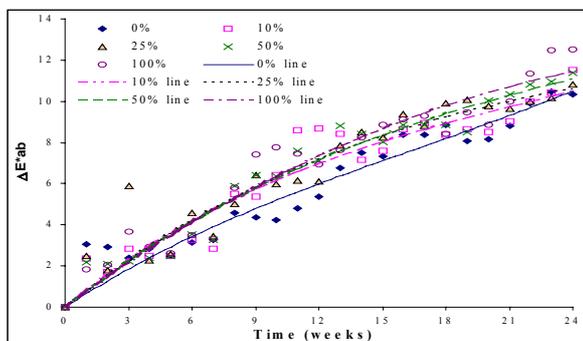
Figure 2. Colour differences of mao juice during storage.
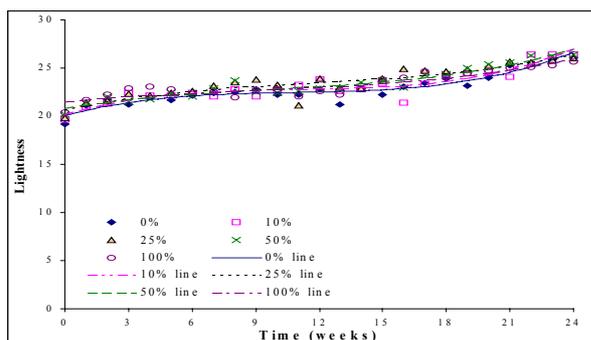
Figure 3. Changes in lightness of mao juice during storage.
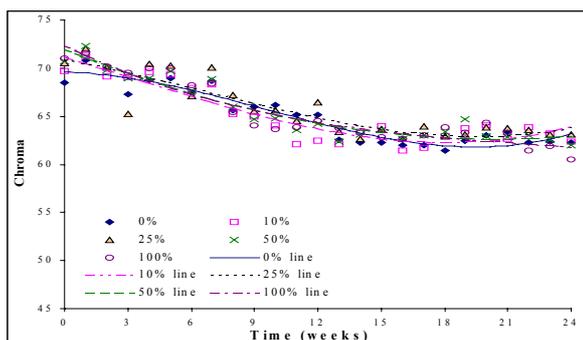
Figure 4. Changes in chroma of mao juice during storage.
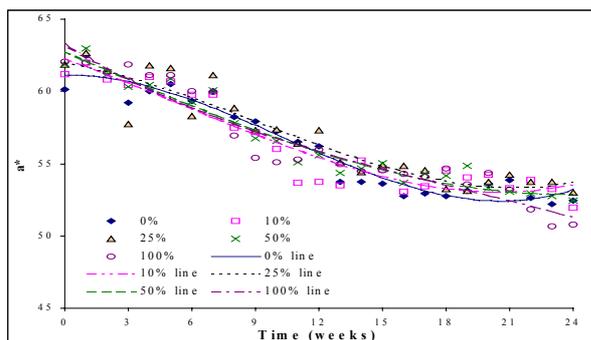
Figure 5. Changes in a* value of mao juice during storage.
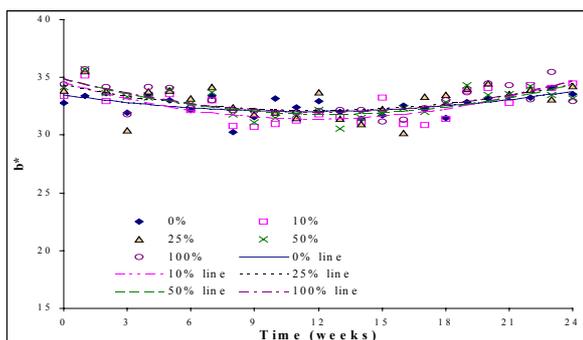
Figure 6. Changes in b* value of mao juice during storage.

Total colour difference (ΔE^*) values between the non-aged (zero days) and storage-aged juice of all samples increased during the storage (Figure 2). The trends of all samples showed slight differences; the mao juice containing 0% vitamin C (control) had the lowest changes in ΔE^* values. This indicated that there was not much difference in colour stability between the

control and the juice with vitamin C added. Over the storage period, the lightness values of all samples tended to increase, while the chroma values decreased (Figures 3 and 4). Similar trends and rates of change in lightness and chroma were also found for all samples. The *a** values of all samples decreased over time, while the *b** values remained quite stable, indicating a decrease in redness of the juice colour (Figures 5 and 6). Again, there was not much difference in trends and rates of changes in *a** and *b** values of all samples. Thus no significant differences in colour-appearance changes were found amongst samples having different amount of vitamin C. The preference in redness and in overall colour ranged from "like slightly" to "like moderately" during the period of storage in each of the samples. Thus it can be concluded that the change in colour appearance of mao juice due to the addition of vitamin C was negligible.

4. CONCLUSIONS

There was marked destruction of anthocyanins and vitamin C in mao juice during storage. The rate of degradation of anthocyanins was higher in the juice containing a larger amount of vitamin C. However, these changes did not yield differences in colour appearance and observers could not detect the changes during colour visual colour analysis.

ACKNOWLEDGMENTS

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The fluorescence of sunprotected white cotton fabrics

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ABSTRACT

Beside the vital and powerful role of sun in our everyday lives the overdose of UV radiation on skin can lead to potential skin damage from exposure to the sun's ray. Compare with visible light that interacts with dyes UV radiation interacts with ultraviolet absorbers and fluorescent whitening agents. Middle UV-rays (UV-B region, $\lambda = 280$-315 nm) causes acute and chronic reactions and damages such as skin reddening or increased risk for other diseases. For such reason it is important to protect the people from the ultraviolet radiation falling on garments and sun-screening textiles such as tends. The level of such protection of fabric depends of a large number of factors as the type of fiber, porosity, density, moisture, color and FWA in the case of white textiles. In this paper cationized cotton fabric was treated with UV reactive apsorber on the base of oxalanilide, Tinofast CEL, to improve the UPF of fabric. Exacust method was applied following peroxide bleaching and optical bleaching procedure. For optical bleaching three stilben derivates as optical brighteness agents were used in wide concentration range. The UV protection factor (UPF) measurements were done using Varian Carry-50 AnAs UV-Vis spectrophotometer, the whiteness degree and yellowness by Datacolor Spectraflash 600 PLUS-CT and relative intensity of fluorescence by Carl-Zeiss Fluorometer. The aim of the paper was to study the FWA's fluorescence changes of sunprotected white cotton fabric.

1. INTRODUCTION

Ultraviolet skin protection by fabrics has been a topic for ten years but UV absorbers have been on the market for over twenty years to protect various substrates (tires, coated fabrics, etc.) against UV degradation or to improve light fastness. Fabric can reflect, absorb and scatter solar wavelengths that reaches the earth's surface in the range of 280 nm to 3000 nm, consisting of UV, VIS and IR radiation (Menter and Hatch 2003). The UV radiation represents 7% of total solar emission. It is divided into UV-A (400-320 nm), UV-B (320-280 nm) and UV-C (<280 nm). UV-B rays are only partially absorbed by ozone and reach the earth causing erythema (sunburn), sun tanning, photocarcinogenesis and "photoaging" although UV-B is a small fraction, about 10% of total UV radiation (Geis et al. 1998, Neves and Neves 2003).

On the basis of good fabric UV protection it is clear that clothing has the ability to protect the skin from incident solar energy. This protection depends on fiber composition and moisture content, type and concentration of dye, optical brighteners and UV-B protective agents. Optical bleached textiles absorb the UV light and remitt it as the bluess, redness and greeness light resullting in the textile that appears whiter (Shenai 1999). According to this fact FWAs on textile can influence on UPF values in the wide range of FWAs concentration (Grancarić and Soljačić 1980).

Ultraviolet protection factor, UPF values (Table 1) indicates the ability of fabrics to protect the skin against sun burning. It indicates how much longer a person can stay in the sun with

the fabric covering the skin as compared with the uncovered skin to obtain same erythemal response. The UPF can be calculated by the following equation (Menter and Hatch 2003):

$$\mathrm{UPF} = \frac{\Sigma E(\lambda) \cdot S(\lambda) \cdot \Delta\lambda}{\Sigma E(\lambda) \cdot S(\lambda) \cdot \tau(\lambda) \cdot \Delta\lambda} \qquad (1)$$

where:

$E(\lambda)$ = spectral weighting function of erythemal action spectra
$S(\lambda)$ = spectral irradiation for appropriate solar radiation spectrum [W m^{-2} nm^{-1}]
$\tau(\lambda)$ = spectral transmittance through specimen
$\Delta\lambda$ = appropriate wavelength measuring interval [nm]

2. MATERIAL AND METHODS

The fabric used was a circular weft knitted fabric S-307 of 100% carded raw cotton (123 g/m^2), 87 cm wide in tubular form, having 11 wale/cm and 14 courses/cm. Fabric was desized, traditionally scoured with NaOH and enzimatically scoured with BioPrep 3000L, than bleached in peroxide baths (Grancarić, Pušić and Tarbuk 2004). Samples were mercerised standard way. Cationization using 3-chlor-2-hydroxy-propyl-trimetyl-ammonium chloride (CHPTAC) was carried out during mercerisation (Grancarić, Tarbuk and Dekanić 2004). Raw and pretreated cotton knit samples were treated with the optical brightener Uvitex BHT (Ciba) in a wide concentration range (0.06% – 6%) and treated with 0.5% of UV absorber Tinofast CEL (Ciba).

Relative intensity of fluorescence was measured on Spekol (Carl Zeiss, Jena) device adapted to measuring fluorescence in relation to the standard (Fluorescence Reference Standard, Datacolor). CIE whiteness and yellowness were measured using spectrophotometer Datacolor SF 600 PLUS-CT and UPF values using transmission spectrophotometer Varian Cary 50 Solarscreen according Australian/New Zeland Standard AS/NZS 4399:1996. Air permeability was measuerd according DIN 53 887.

3. RESULTS AND DISCUSION

The paper investigates the fluorescence of sunprotected white cotton fabrics after preparatory finish, optical bleaching and treating fabric with an ultraviolet protective agent, Tinofast CEL. Fabric weigth (m_k), air permeability, relative intensity of fluorescence (ϕ_{rel}), degree of whiteness (WB), yellowness index (YI) and UV protection factor (UPF) were determined.

Table 2. Labels, treatments, fabric weight, air permeability and yellowness index.

Label	Treatment of Cotton Sample	m_k [g m^{-2}]	Air permeability [dm^3/h/m^3]	YI
S	Untreated	123	40.00	24.25
B	Scoured and bleached	154	22.50	5.58
EB	Enzymatically scoured and bleached	154	24.00	5.19
BM	Scoured, bleached and mercerised	188	20.00	10.88
EBM	Enzymatically scoured, bleached and mercerised	218	16.36	10.76
BMK	Scoured, bleached, mercerised and cationized	234	16.36	12.24
EBMK	Enzymatically scoured, bleached, mercerised and cationized	231	13.85	11.81

As shown in Table 2, the weight and air permeability values indicate the high shrinkage of mercerised and cationized fabrics. Weaker transmission of UV light through a more tight knitted fabric increases UPF to maximum values of 1000 (Table 3).

The relative intensity of fluorescence (ϕ_{rel}) of untreated and treated knitted fabrics with different FWAs concentrations, and with UV absorber are shown in Figure 1 a) and b). The CIE whiteness for all samples is shown in Table 3. The relative intensity of fluorescence shown in Figure 1a and b indicate that the mercerised and catonized knitted fabrics give the highest fluorescence in the whole concentration range. They absorb the highest amount of the optical brightener compare to untreated and chemical bleached samples. Fabrics treated with UV absorber show the lower fluorescence than untreated ones. Mercerised and catonized fabrics show the highest fluorescence in all cases.

a   b
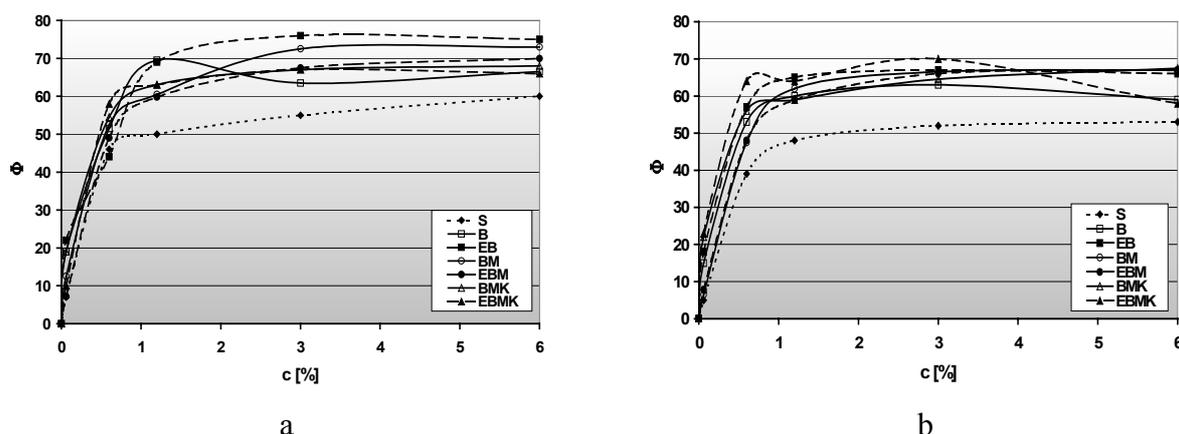
Figure 1. The relative fluorescence intensity of cotton fabric treated with a) FWA and b) FWA and UV absorber vs. FWAs concentration.

One more phenomenon can be seen in Figure 1 and in Table 3. Increasing the FWAs concentration higher than optimal one decrease the intensity of the fluorescence. It is result of well known bathochromic shift of the remission spectrum. As well CIE whiteness is decreasing. The whiteness of the knitted fabric shown in Table 3 indicates that concentration of Uvitex BHT 1.2% (o.w.f.) is the optimum one for this optical brightner.

Table 3. CIE whiteness of fabrics treated with FWA and after treated with UV absorber.

Cotton Sample	c [%]										
	0	0.06		0.6		1.2		3.0		6.0	
	-	-	UV	-	UV	-	UV	-	UV	-	UV
S	9.9	59.4	46.2	88.6	79.7	85.1	83.3	84.5	80.7	71.3	74.4
B	66.9	106.7	81.6	128.8	111.1	127.5	116.3	117.4	111.2	102.5	97.1
EB	67.6	120.7	100.7	143.9	128.1	144.2	128.8	134.1	122.1	118.7	114.2
BM	51.4	87.8	69.3	117.8	99.8	111.3	101.6	108.2	104.4	97.1	98.8
EBM	53.9	57.6	62.1	74.1	93.0	103.8	99.3	118.6	105.5	114.5	104.6
BMK	47.3	88.1	67.8	109.1	103.8	115.1	98.8	105.8	99.2	104.6	81.9
EBMK	48.2	93.5	85.2	121.0	115.9	129.6	106.1	109.4	94.7	105.7	70.3

The evaluation of the protection of the knitted fabric against UV radiation is shown in Table 4 by the UPF values according to AS/NZS 4399: 1996. Untreated knitted fabrics have relatively low UPF values. Cationized knitted fabrics have the maximum UPF value (UPF = 1000), what means that cationization itself make excellent UV protection. Although expected, the samples of the highest fluorescence (Φ_{rel}) and highest whiteness degree (WB) are not

those having the highest UPF. It seems that knitted fabric tightness play a major role in this context as discussed above. For mercerized and cationized cotton knitted fabrics it is important that maximum UV protection does not decrease after FWA and UV treatment.

Table 4. UPF values of fabrics treated with FWA and after treated with UV absorber.

Cotton Sample	c [%]										
	0	0.06		0.6		1.2		3.0		6.0	
	-	-	UV	-	UV	-	UV	-	UV	-	UV
S	7.8	16.4	17.3	29.4	35.3	18.2	37.3	29.1	55.7	34.6	74.2
B	8.3	12.2	19.6	31.4	61.1	82.8	74.7	59.7	156.8	106.9	190.2
EB	9.3	10.6	14.7	40.0	64.0	85.8	59.9	116.7	66.2	71.9	140.4
BM	18.1	16.1	22.8	78.2	96.9	143.1	91.1	167.9	87.9	1000	986.6
EBM	16.9	14.3	20.1	35.7	31.0	131.0	53.1	781.3	151.2	999.8	587.8
BMK	20.1	57.8	52.0	996.3	994.8	1000	1000	1000	1000	1000	1000
EBMK	20.9	26.8	52.5	1000	1000	1000	1000	1000	1000	1000	1000

4. CONCLUSION

In each wet treatment cotton swells what leads to shrinkage of knitted fabric. Shrinkage of knitted fabric increases its tightness, and a weaker transmission of UV radiation through tighter fabrics is the reason for their better protection against UV rays.

By increasing the concentration of optical brightener the intensity of fluorescence rises, whereas whiteness decrease. The fabrics that show the highest fluorescence and whiteness do not show, at the same time, the highest UPF values. Optical brightener insures high protection against UV radiation in cotton fabrics. By treating the optically bleached cotton with an UV protective agent in low concentration range of optical brightener, the synergetic effect of both agents on UV protection is observed, while at high concentrations of optical brighteners an antagonistic action is provoked causing reduced UPF-values.

Maximum UV protection of cotton knitted fabrics accomplished during processes of mercerization and cationization does not drop after optical bleaching or ultraviolet protection.

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Visual assessment of UV radiation by colour changeable textile sensors

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ABSTRACT

Sunburn, skin cancer, premature aging, and suppression of the immune system are some of the harmful effects of acute and cumulative exposure to ultraviolet radiation (UVR). A decrease of 1% in ozone would lead to increases in the solar UVR at the earth's surface and may eventually lead to a 2.3% increase in skin cancer. Wearing clothing, hats, and other protective apparel during sun exposure may reduce risks associated with overexposure. However, fabrics used in summer time apparel often provide poor protection against solar UVR, because they are usually made from light to medium weight fabrics.

Our contribution is not to develop new UV protective materials, but to use with advantage well-known photochromic dyes or pigments for constructions of new textile based sensors as integrated parts of summer clothes. In our study we would like to detect not only UV radiation with sensors as indicators but also detector of quantity UV radiation dose. We have prepared for this study concentration scale of different UV absorbers and different photochromic dyes. We will show comparison of sensitivity modulation of our UV textile based sensors with measuring units (spectroradiometers) and reproducibility.

1. INTRODUCTION

In the present time, the increase of harmful pollutants in the environment make our living conditions worse, and can produce non-reversible damage on our health and jeopardize the full quality of our life. Big attention is given to research, development and perfection of protective clothes, specially their barrier features. By protective barriers we understand how the clothes or textiles protect the wearer against the above-mentioned dangerous conditions and if the protection is only partial or the protection is time limited by ambient conditions. Most of the protective clothes are not developed for long time wearing. During the development of these barrier structures we have to keep in our mind full comfort of acting persons without limitation. Some of the protective clothes are equipped with electronics, sensors or devices, which are monitoring and quantify dangerous substances in the environment. In the present time big attention is given to miniaturization of electronics and also flexibility of their connection with computing units (Tao 2001).

Above mentioned describe concept of protective clothes we call as intelligent structure. Disadvantage of this intelligent structure is no adequate response on the external stimulus, there is only monitoring of external dangerous conditions. This structure we call passive *intelligent* textile structure.

Sensors and textile structures that produce adequate responses and are able to modulate the protective degree in accordance to the external stimulus (change of intensity UV, temperature, press, electrical field, etc.) are called *smart* textiles. An example of passive intelligent textiles are optical fibres, which are leading not only the signal but are also sensitive to the

deformation, concentration of substances, press, electric power, etc. An example of active intelligent textiles could be textiles which react by change their own colour in dependence on external stimulus (light, temperature). They are called chameleonic textiles or heat containing textiles, which are able to store or slack energy according to the external temperature. Moreover, textile based sensors and active protective textiles have the advantages that their textile structure is easy customisable by sewing, thermal bonding or gluing. Also there are advantages of easy maintaining (washing, chemical drying) and low specific weight with good strength, tensibility and elasticity. Good features are also workability without change of technology of production and extremely large specific surface. Big advantages are possible integration of these types of sensors into systems of protective clothes, and also their price and availability. For these reasons, this article is directed to the research of textile-based sensors with photochromic behaviour, respectively to study the dynamic behaviour and the modulation of sensitivity of photochromic sensors.

In this work, a new definition of colour reversible hysteresis is described, by hysteresis of colour change curve. This colour hysteresis curve is described by a kinetic model, which defines the speed of colour change initiated by the external stimulus: UV light. Kinetic model verification is done for textile sensors with photochromic pigment applied by textile printing, fibre mass dyeing.

2. MATERIAL AND METHODS

Our experiment was divided into 3 parts, and every part is directed to a special form of application of photochromic pigments and the study of photochromic behaviour from the point of kinetics and dynamics in different mediums:

a) Application of photochromic pigments by textile printing - PTP
b) Application of photochromic pigments by mass dyeing - NWT
c) Study of photochromic pigments behaviour in solution - PPS

In our research, we follow the development of simple textile based sensor sensitive to UV light and the kinetic study of behaviour. Main attention was given to the possibility of using the technology of textile printing by stencil printing. This experiment was completed by the study of the influence of UV absorbers and ability of properties modulation of sensors. Also, the dependence of colour change intensity on the concentration of photochromic pigment was studied. The above mentioned studies were completed by the study of fatigue resistance in dependence on the intensity of the source and the time of exposition, including also classic tests of light fastness on xenon test and dry staining fastness, which are the same as for normal classic pigment use in textile finishing and these tests are also limitation of application offered sensors.

In the second part of our experiment was studied change of photochromic behaviour tested pigments in non-woven textiles produced by technology Melt Blown (mass dyeing) and in third part was checked the photochromic behaviour used pigments in solution via measurement of transmission characteristics as completive study how is changed the photochromic response via kind application. For the experiment, commercial photochromic pigments PPG-Photosol 33672 (P1), PPG-Photosol 7106 (P2), PPG-Photosol 749 (P3), PPG-Photosol 0265 (P4) and PPG-Photosol 5-3 (P5) were used. Chemical structure illustration is shown on Figures 1 and 2 (Van Gemert 2004).

As it was mentioned, in our experiments two kinds of solid media —textile substrate with photochromic pigments— were prepared. Illustrations of fixation of photochromic pigments on the textile substrates are shown on Figures 3 and 4.

| *Figure 1. P1 structure.* | *Figure 2. P3 structure.* |

| *Figure 3. NWT with P3.* | *Figure 4. P3 print on PET.* |
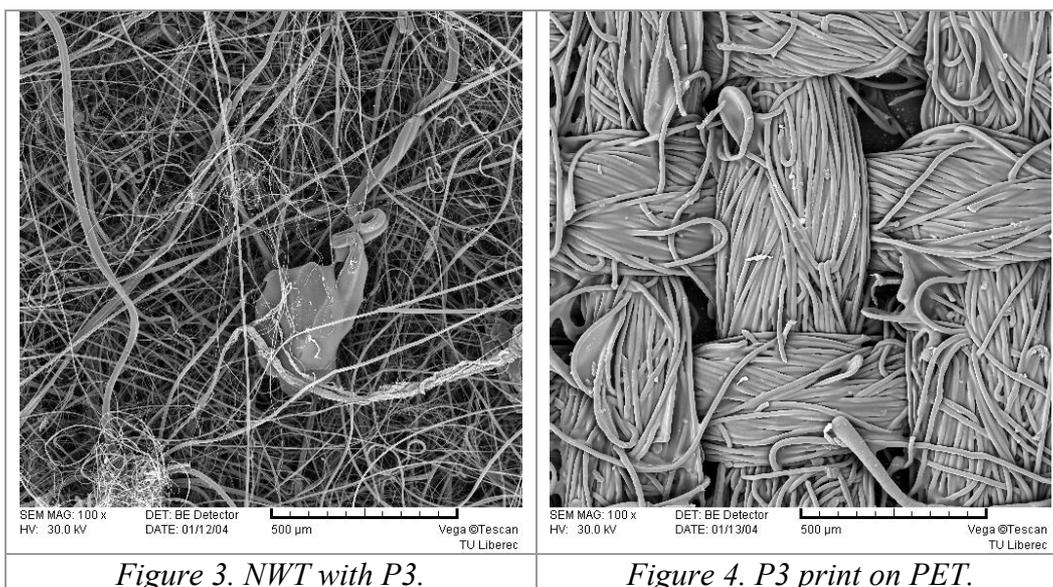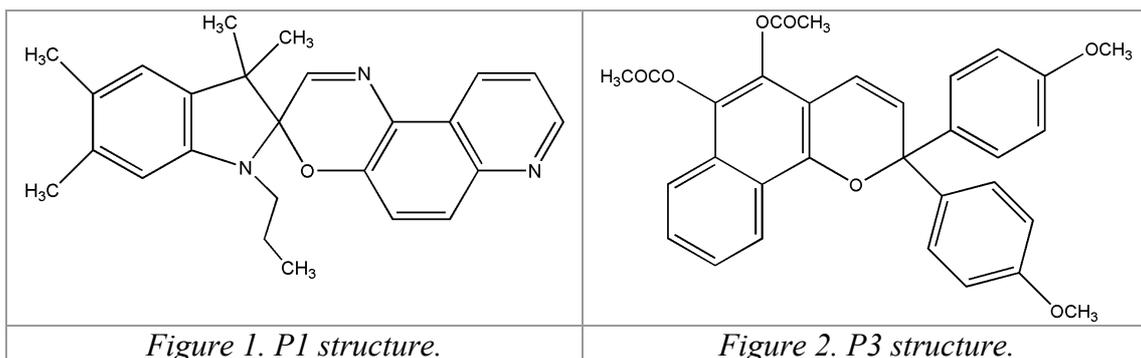
Besides measurements of prints and NWT via classical spectrophotometer Spectraflash 300UV was used arrangement of AVANTES S2000 spectrometer due to short time, continuous measurement respectively. S2000 arrangement make possible using different light sources for tested samples illumination. Same possibility was obtained via modification of CS-5 spectrophotometer for measurement of photochromic solutions.

Because the relationship between remission and concentration of colorant agent is non-linear, in colour measurement is obviously used relation between Kubelka-Munk function (*K/S*) and concentration, colour change intensity *I* respectively. Colour change intensity, *I* that we used, is defined as following equations:

$$I = \int_{400}^{700} K/S_\lambda d\lambda$$

For description of kinetic behaviour of our UV sensors we used first class kinetic model as is shown in following equations (Viková 2003):

Exposition: $I = I_\infty + (I_0 - I_\infty).e^{(-kt)}$ Relaxation: $I = I_0 + (I_\infty - I_0).e^{(-kt)}$

From these equations it is possible to calculate halftime of colour change $t_{1/2}$ (Rais 1968) and colour hysteresis area *Hp*:

$$t_{1/2} = \frac{\ln 2}{k}.60 \quad,$$

$$H_P = \int I_\infty + (I_0 - I_\infty)e^{-kt}dt - \int I_0 + (I_\infty - I_0)e^{-kt}dt$$

It is evident from equation (6) that colour hysteresis area *Hp* arise by time reverse of reversion data, as shown on the Figure 6.
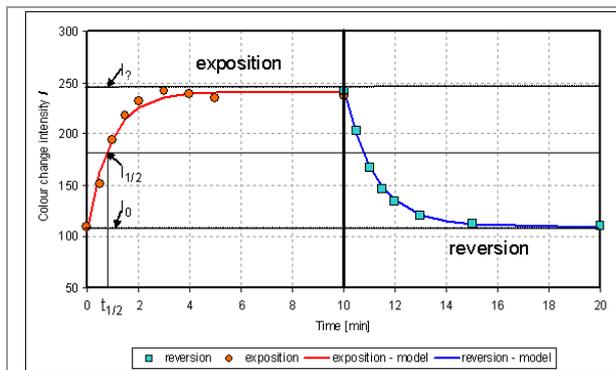
| *Figure 5. Typical growth and decay processes of colour change intensity for sample illumination of 714,6 μW.cm-2 power.* | *Figure 6. Colour hysteresis area* Hp *construction for sample at same condition as Figure 5.* |
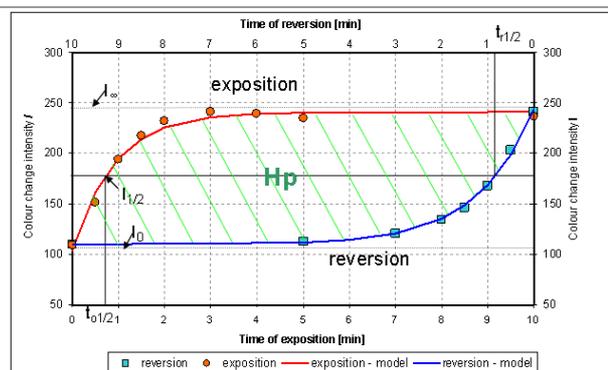
3. RESULTS

Data on both Figures 5 and 6 were obtained for lowest intensity of illumination *E* (979.3 lx). On the Figure 6, we can see that already for this *E* in the colour change speed is higher during of exposition than reversion phase. In our study we prepare new view on the relationship between intensity and time of exposition, time of relaxation respectively. The name of this new kind of graphs is colour hysteresis area *Hp*. When we test the relationship between halftime of colour change $t_{1/2}$ and intensity of illumination *E*, we obtain decreasing linear relation (Figure 7). That means time of colour change is shorter during intensity of illumination increasing.
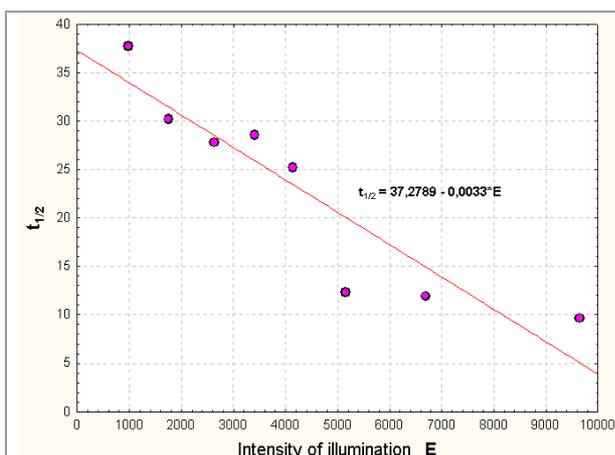
| *Figure 7. Halftime of colour change* $t_{1/2}$ *relation on intensity of illumination.* | *Figure 8. Colour hysteresis area* Hp *relation on intensity of illumination.* |
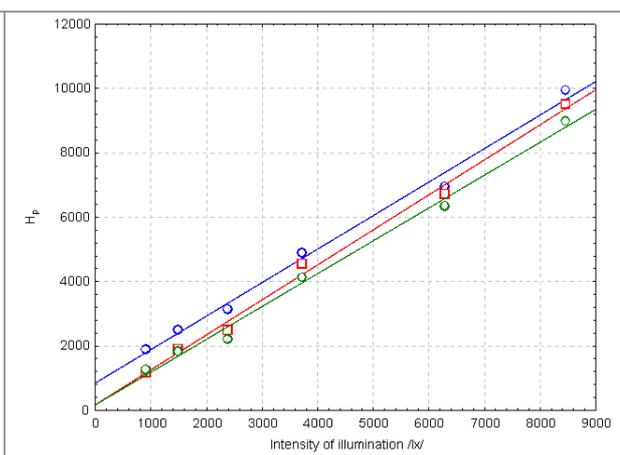
Linear relation we obtain also via dependency of hysteresis area on intensity of illumination *E*. Figure 8 shows dependences hysteresis area relation to UV absorber dose also. It is evident that increasing of UV absorber dose gives decreasing of *Hp*.

As was mentioned before used measuring units were prepared for measuring colour change of tested samples under different light sources. Figures 9 and 10 show results for photochromic pigments solutions PPS and prints PTP.

| *Figure 9. Change of PPS colour position dependent on different light source.* | *Figure 10. Change of PTP colour position dependent on different light source.* |
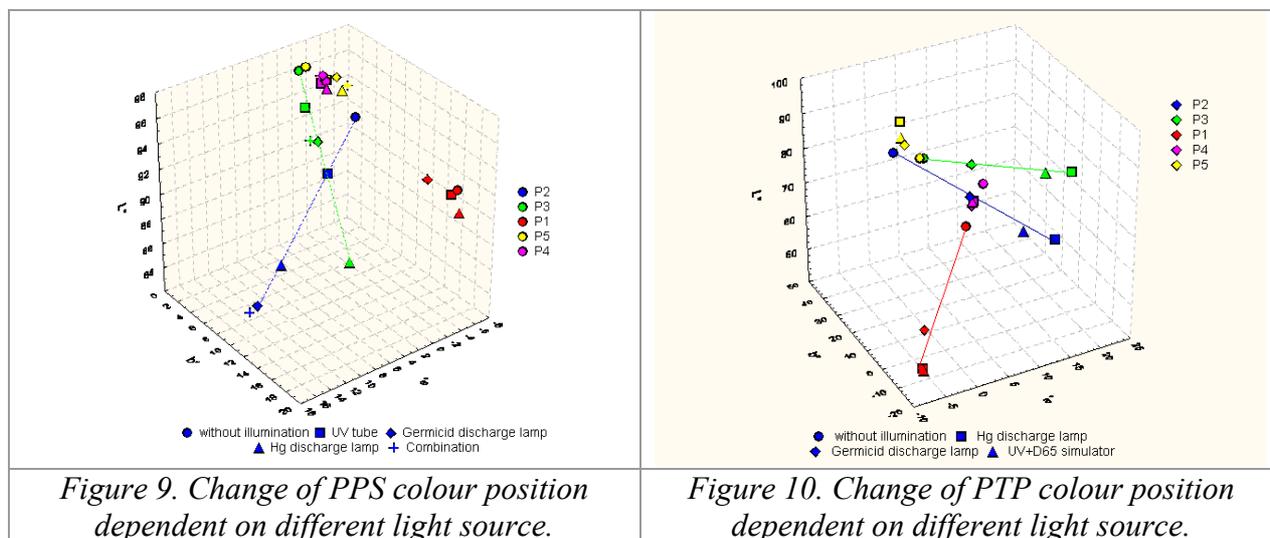
4. CONCLUSION

This paper introduces the study of dynamic properties of photochromic textile sensors. In our study we prepare new view on the relationship between intensity and time of exposition, time of relaxation respectively. That means colour hysteresis area *Hp* is linear related to the intensity of illumination *E*. Via this relation we demonstrate the possibility of flexible textile-based sensors construction in area identification of radiation intensity. Beside of this one, we demonstrate differences between photochromic pigments behaviour in solution and prints on textiles: differences between spectral power distribution of light source sensitivity of this one's. Bi-exponential functions, which are used in *Hp* calculation, well described the kinetics of colour change intensity of photochromic pigments. They give good fits to the growth curves as well as to the relaxation ones.

ACKNOWLEDGMENT

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Instrumental whiteness evaluation:
Practical results of inter-instrument agreement tests

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ABSTRACT

The instrumental evaluation of white objects treated with fluorescent whitening agents, such as commonly found on substrates like textiles, plastics and paper, is a task not as straightforward as it might seem (ASTM 1992, Hayhurst and Smith 1995). One of the main reasons is the fluorescence of the fluorescent whitening agents (FWA) that is influenced by the amount of UV radiation in relation to the amount of radiation in the visible range of the spectrum available in the sample illumination. This makes it necessary to perform a UV adjustment on the light source in reflectance spectrophotometers to establish the adequate ratio of UV and visible radiation. This study compares whiteness measurements of textile samples treated with fluorescent whitening agents made on 4 different industrial reflectance spectrophotometers, some using a traditional method of adjusting a UV filter position and others performing a numerical and virtual UV control. Two sets of standards were used for the calibration and the measurement results obtained after the different calibrations are compared.

1. UV ADJUSTMENT AND UV STANDARDS

For instrumental evaluation with reflectance spectrophotometers the spectral power distribution of the light source, usually a pulsed Xenon lamp, is rarely known to the industrial user, who generally simply adjusts the UV content of the flash during a so-called "UV calibration". There are two types of UV adjustment, the traditional filter method introduced by Gärtner in the 1970's (Gärtner and Griesser 1975) and the numerical UV control patented by Imura (Imura 1997, USPTO 1977, 2000).

For this UV adjustment it is necessary to use a fluorescent standard with known calibration values, and at present there are different standards available: paper, Teflon, plastic and textile standards. The textile standards used in this study were produced and calibrated by the Textilforschungsinstitut Thüringen-Vogtland (TITV), Germany. Two sets each of the cotton (CO) and polyester (PES) were used. The calibration data available in the certificate are the CIE whiteness value, the Ganz-Griesser whiteness value (Ganz 1972) and the spectral radiance factors for the five standards. This allows for the UV adjustment to be done according to any of the three types of calibration values.

2. SAMPLES, INSTRUMENTS AND SETTINGS

The samples measured in this study are lightweight woven textile samples with a very similar structure: one sample is a polyester/cotton mixture treated with a FWA, one sample is a 100% cotton bleached fabric without FWA, six samples use the fabric of the previous sample as substrate to which two different kind of FWAs and fractions of four different dyes where

applied to produce different tints and five standards each of the cotton and the polyester standard scale were also measured as samples.

Four industrial spectrophotometers, produced by Konica Minolta, were used for the measurement of the textile samples, all of them with a sphere geometry: two bench-top instruments that make use of the traditional filter adjustment for the UV setting, two CM-3720d spectrophotometers, and two instruments with numerical UV control, a portable CM-2600d and a bench-top CM-3600d.

The 18 samples were measured on the 4 industrial instruments after having performed the adjustment of their UV setting. On the two filter instruments the calibration was done according to the CIE whiteness value (W-CIE) of the whitest standard of the scale and also according to the Ganz-Griesser whiteness value (W-GG) of the same sample. As mentioned previously, four calibration scales were used, a cotton and a polyester scale that were purchased 8 months before being used for this study (identified as original scales) and another cotton and polyester scale that were used immediately after their arrival (identified as new scales). All the measurements were done during the same week. Table 1 shows the different percentages of UV obtained as result after the different types of calibration.

Table 1. Comparison of UV setting (%UV).

Scale	Instrument	Cotton scale		Polyester scale	
		W-GG	W-CIE	W-GG	W-CIE
Original	3720-1	87.3	96.0	90.8	99.9
	3720-3	88.5	99.9	99.9	99.9
New	3720-1	82.1	84.7	82.1	84.7
	3720-3	82.6	86.8	72.8	85.4

Depending on the standard and on its calibration values used for the UV adjustment a different percentage was determined as being the adequate. In general the UV setting was lower for the new scales. This indicates that the FWA of the original scales probably had already deteriorated due to extensive use and more UV energy was required from the lamp to excite the fluorescence necessary to achieve the indicated whiteness value.

3. MEASUREMENT RESULTS

After having adjusted the instruments as mentioned previously, the samples were then measured. The 10 "samples", five standards each of the cotton and the polyester calibration scales, were measured and compared to their values as given in the calibration certificate. Table 2 shows the average differences from the calibration values of the standard samples measured on the different instruments/settings. Calibration with the original scale is slightly better than with the new scale and the cotton scale also resulted in a smaller difference from the calibration values than the PES scale.

Table 2. Average absolute difference from calibration values.
Comparison of calibration options.

original scale	1.6	new scale	2.4
filter adjustment	2.0	NUVC	2.0
CO scale	1.8	PES scale	2.2

The comparison of the three different whiteness values in Table 3 shows that the adjusted instrument-specific parameters lead to better W GG results than the standard values. These W GG adj values are better than the W CIE values, especially when taking into consideration that the W GG and W CIE scales are different. An evaluation as a percentage of the average whiteness value in the certificates, as shown in the right-hand column of Table 3 is more adequate.

Table 3. Average absolute difference from calibration values.
Comparison of evaluation options.

average Δ	W	%
W CIE	1.5	1.3
W GG std	3.1	2.2
W GG adj	1.4	1.0

A second requirement, apart from a measurement error as small as possible, where one expects the measurement results to be as close as possible to the calibration values, is the reproducibility amongst instruments. The same sample measured on different instruments should lead to results as similar as possible. The standard deviation of the average measurement results obtained on the four instruments shown in Table 4 is reasonably small. For the Ganz-Griesser whiteness values the adjusted parameters lead to closer results amongst the instruments, as is the purpose of the adjustment.

Table 4. σ of average measurement results. Comparison of whiteness formulae.

σ	original scale	new scale
W CIE	1.7	1.5
W GG std	3.1	3.0
W GG adj	2.9	1.7

4. CONCLUSIONS

The study confirmed that it is really necessary to adjust the UV radiation of the sample illumination when fluorescent samples are to be measured, a basic fact not always so obvious for the industrial user. It shows that it is necessary to adjust the instrument-specific parameters when using the Ganz-Griesser whiteness formula. If for some reason this not possible it is then more appropriate to use the CIE whiteness formula than to use the standard parameters for the Ganz-Griesser whiteness formula.

Comparing the two different types of UV setting, the filter adjustment and the numerical UV setting, it can be said that both lead to good results. From a user's point of view the NUVC is much faster and easier.

We found that the portable instrument is highly compatible with the bench top instruments, even when measuring FWA-treated samples.

Our results show that the inter-instrument agreement of instrumental whiteness evaluation might not yet be as good as desirable, but compared to the visual reproducibility these results are already a significant improvement, considering that a group of observers was able to repeat their own whiteness evaluations only in approximately 50% of the cases (Gay 2004).

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Industrial colour difference evaluation: LCAM textile data

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ABSTRACT

This paper aims to give a brief review of problems occurring in the developing of colour-difference formulae. Most of the problems mentioned are well known, but are often forgotten. Numerous studies on colour-difference evaluation have been performed and colour-difference formulae are being modified again and again towards practical applications. The basic issue is how to make the colorimetric magnitude represent the visual one. One of the most important aspects is the relationship between measured colour-differences and perceived scales, which is usually assumed linear for a practical use in industry.

The work in the area of colour differences has concentrated on collecting reliable data and developing equations that describe the perceived colour-difference results. Newer equations have been developed on base of the CIELAB (CIELCH) colour space with application weighting difference components such as ΔL^*, ΔC^* and ΔH^*. Weighting functions SL, SC, SH are computed from regression analysis used linear (CIE1994) or hyperbolic model (CMC(l:c)).

In this paper, based on the psychophysical method of paired comparison, an experiment for testing the visual colour difference in relation to colorimetric scales is presented to analyse the relationship between colour discrimination threshold and supra-threshold colour-difference perception and its use in industry. Firstly, actual colour-difference formulae CMC(l:c), DCI1995, DIN99, CIE2000 and MV-1 are discussed.

1. INTRODUCTION

Considerable work has been accomplished in terms of colour difference perception comparing single coloured patches. In 1942, MacAdam wanted to test the linearity of errors in the colour matching experiment. He discovered that colour differences are not linear. The most widely used colour difference equations in the last decades are CIELAB and CIELUV colour difference equations recommended in 1976 by the CIE. In both CIELAB and CIELUV colour spaces, the colour difference ΔE^* between two arbitrary colours is defined as an Euclidian distance in a uniform space comprising a lightness L* axis and red-green, yellow-blue opponent colour axes using rectangular coordinates. The colour differences in CIELAB colour space are given by equation 1:

$$\Delta E^* = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \tag{1}$$

where a* and b* are the redness-greenness and yellowness-blueness scales in CIELAB colour space. The colour difference formula CIE 76 is in many cases not adapted to human perception. The work in the area of colour differences has concentrated on collecting reliable

data and developing equations that describe the perceived colour-difference results. Newer equations have been developed on base of the CIELAB (CIELCH) colour space with application weighting difference components such as ΔL*, ΔC* and ΔH*. Weighting functions SL, SC, SH are computed from regression analysis used linear (CIE1994) or hyperbolic model (CMC(l:c)). During the development of new colour-difference formulas (CIE1994, C94CHR and MV-1(l:c)) there was considerable discussion about possible hue dependencies, as exemplified by the CMC (Clark, McDonald and Rigg 1984) and BFD (Luo and Rigg 1987) equations. The CMC (l:c) colour-difference formula was a refinement of the JPC79 equation developed by McDonald (1980). McDonald found that, for brown and purple-blue colours, CIELAB tolerances were over predicted. Therefore hue-angle dependent correction was implemented in CMC equation. The BFD colour-difference formula was based on the Luo-Rigg (BFD) dataset. Luo-Rigg found that green colours were also over predicted. Bern's studies on RIT and Du Pont dataset (Berns et al. 1991) showed that this hue dependency is not necessary condition by development of a new colour-difference formula. Based on this study the CIE1994 colour-difference equation was adopted, with the general form (2):

$$\Delta E = \sqrt{\left(\frac{\Delta L*}{k_L W_L}\right)^2 + \left(\frac{\Delta C*}{k_C W_C}\right)^2 + \left(\frac{\Delta H*}{k_H W_H}\right)^2} \qquad (2)$$

However last statistical analyses of different colour-difference datasets corroborate an existing hue-angle dependent function or derive a new function (Vik 1997, Kim and Nobbs 1997, Luo, Cui and Rigg 2001). All these correction formulae have a disadvantage that they correct the differences and therefore violate the vector definition of a colour difference in a colour space. An example of hue dependency correction of colour difference calculation is seen on the MV-1 colour difference formula (Vik and Viková 1999):

$$\Delta E_{MV-1} = \sqrt{\left(\frac{\Delta L*}{l S_l}\right)^2 + \left(\frac{\Delta C*}{c A_c}\right)^2 + \left(\frac{\Delta H*}{A_h}\right)^2 + \frac{\Delta C* \Delta H*}{A_d}}, \qquad (3)$$

where

$$S_l = \frac{1,358964 + 0,016071.L*}{2} \qquad Ac^2 = \frac{Sc^2.Sh^2}{\cos^2(\Delta\theta 3COS)Sh^2 + \sin^2(\Delta\theta 3COS)Sc^2}$$

$$Ad = \frac{Sc^2.Sh^2}{\sin(2\Delta\theta 3COS)[Sh^2 - Sc^2]} \qquad Ah^2 = \frac{Sc^2.Sh^2}{\sin^2(\Delta\theta 3COS)Sh^2 + \cos^2(\Delta\theta 3COS)Sc^2}$$

$$Sc = 0,9304 + 0,058646.C* \qquad\qquad Sh = 0,7607 + 0,017561.C*$$

$$\Delta 3COS = 4,48 + 8,89\cos(h_{ab} + 66,09) - 10,22\cos(2h_{ab} + 43,18) + 11,42\cos(3h_{ab} - 80,01)$$

weightings coefficients are for slightly textured surface (textiles) l=2, c=1.

Another possibility to make a correction of CIELAB colour space non-uniformity is Rohner and Rich solution, which was published at the AIC conference 1995 in Berlin as DCI-95 colour difference formula (Rohner and Rich 1995). Based on this recommendation DIN99 was developed. The new DIN99 colour difference formula, instead, describes a non-linear transform the colour coordinates of the CIELAB colour space (Witt 2001):

$$\Delta E_{DIN99} = \sqrt{(\Delta L_{99})^2 + (\Delta a_{99})^2 + (\Delta b_{99})^2}, \qquad (4)$$

where L99, a99, b99 are DIN 99 colour coordinates.

Both of these approaches were accepted in CIE2000 colour-difference equation adoption:

$$\Delta E_{CIE2000} = \sqrt{\left(\frac{\Delta L'}{k_L S_L}\right)^2 + \left(\frac{\Delta C'_{ab}}{k_C S_C}\right)^2 + \left(\frac{\Delta H'_{ab}}{k_H S_H}\right)^2 + R_T \left(\frac{\Delta C'_{ab}}{k_C S_C}\right)\left(\frac{\Delta H'_{ab}}{k_H S_H}\right)} \qquad (5)$$

2. MATERIAL AND METHODS

In the Colour and Appearance Measurement Laboratory (LCAM DTM TF TU Liberec) a dataset on wool/polyester plain weave with a smooth surface was prepared. The distribution of colour samples in the CIELAB colour space is shown in Figure 1.

Figure 1. LCAM colour difference data set.
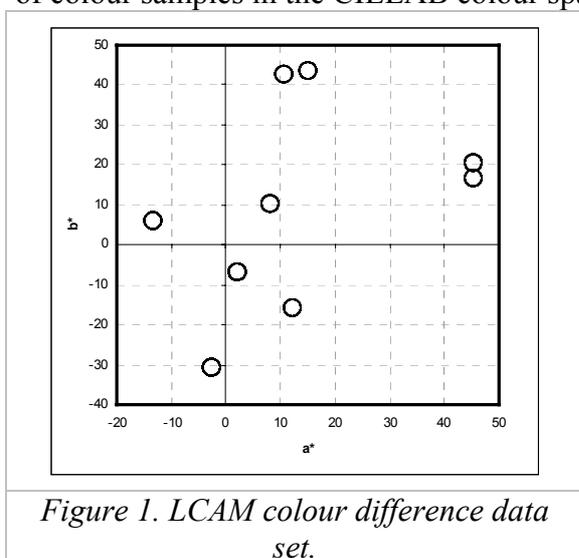
Standards were prepared using three dyestuffs. The samples around each standard were obtained by variations between each position in laboratory dyeing machine, decreasing and increasing the concentrations of the dyes. The samples are, therefore, essentially non-metameric to standards. Each colour-difference pair was prepared from 5.5 × 4.0 cm^2 cut rectangular samples attached to stiff cardboard side-to-side with a hairline separation between them. The sample pairs were measured with a spectrophotometer in specular component excluded (SPEX) and UV included modes. In each pair, CIELAB co-ordinates of samples and the colour-difference were calculated for the illuminant D65 and the 10° observer. Instrumental measurements were repeated 3 times throughout the visual tests period. The error (standard deviation) in measured colour-difference value was 0.17 ΔE* unit. Observations were performed in a lighting cabinet with approximate 0/45 illuminating/viewing geometry. The simulated fluorescent daylight had a correlated colour temperature of 6500 K, and the lightness (L*) of cabinet's background (bottom) was Munsell N7 colour. Eighty-seven colour normal observers assessed each test colour-difference pair against the grey scale, which was produced following ISO 105-A02, fastness testing for assessing change in colour. The observational task was picking the grey-scale pair thought to be closest in magnitude to the test pair. An equation relating GS to corresponding visual difference (ΔV) was: $\Delta V = -0{,}557 + 26{,}59 e^{-GS/1{,}527}$. The visual experiment was conducted in a darkened room. Each observer repeated the experiment five times.

3. RESULTS

The ΔE values from colour-difference formulas were calculated using L*a*b* values for batch and standard. All equations mentioned above were entered to Microsoft Excel. It is possible to change all entering parameters. These calculated ΔE were compared with ΔV values via different evaluation parameters (Vik 2003).
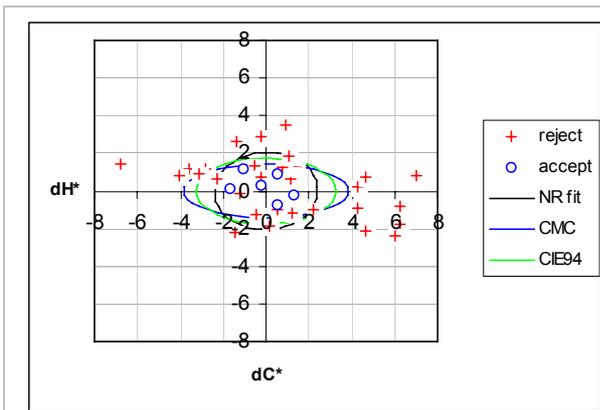
| *Figure. 2 Fitting of LCAM data in dC*dH* plane – red colour centre.* | *Figure 3. Fitting of LCAM data in dC*dH* plane – blue colour centre.* |
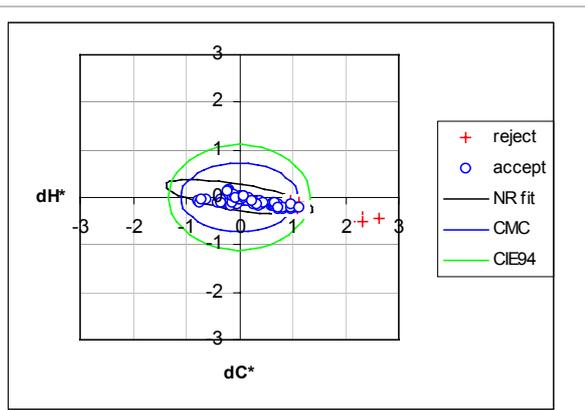
Figures 2 and 3 show fitting of LCAM data in red and blue colour centres for equations CMC, CIE1994 and non-linear fitting. We can see differences between both colour centres – in red colour centre are both published equations applicable. In our experiment with small differences of samples around blue colour centre is shown, that colour tolerances for CMC and CIE1994 are two or three times higher as for ideal colour difference formula (non-linear fitting). Figure 4 shows that best results give MV-1 equation. DCI95, on the other side, has worse prediction ability to LCAM dataset. This problem is caused by recommended adjusting coefficient, which was fitted to Hohenstein colour difference dataset.

4. CONCLUSION
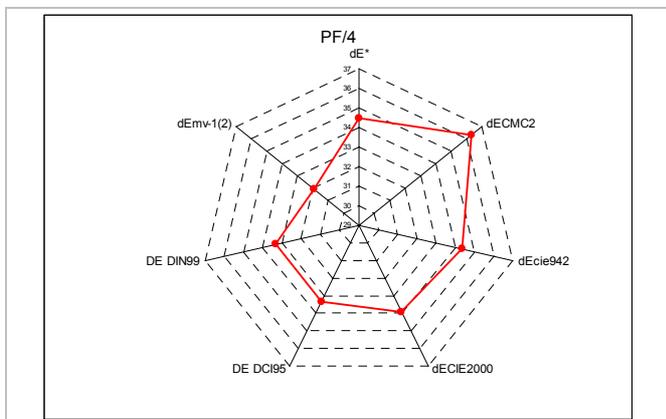
Figure 4 Comparison of equation's performance.

In summary, the last few years have, in our opinion, seen significant improvements in the prediction of the magnitude of perceived colour differences, by the use of several CIELAB-based formulas. Of course, much more research needs to be done within this topic, by analysing specific parametric factors, such as those affecting the optimal weighting function for lightness differences, etc. Discrepancy against equations with and without hue-angle correction is relatively low; therefore, the next developing of a new colour-difference formula must be directed on this point of colour science. Ideally, the model form should have some physiological basis.

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Performance analysis of different optoelectronic imaging sensors for applications in color measurements

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ABSTRACT

Digital image capture devices cannot be used directly as instruments for color measurements because the RGB digital data are not XYZ tristimulus values. The main stages to characterize a digital image capture device as an instrument for color measurements are the spectral and spatial characterization and the color transformation from the RGB device dependent space to a device independent space as CIE-XYZ. In this work we analyze the performance of different optoelectronic imaging sensors in order to transform them into instruments for color measurements. We have compared CCD cameras with different bit-dephts (8, 10 and 12 bits), different color architectures (3 sensors and 1 sensor) and a CMOS camera. Spectral characterization was obtained experimentally measuring the optoelectronic conversion spectral functions, that is, the digital response versus spectral exposure curves. From these curves it is possible to obtain the spectral sensitivities and the color-matching functions. Spatial characterization was obtained experimentally applying a new flat-field correction procedure. Finally, a transformation between the color-matching functions of the image capture device and the color matching functions of the CIE-XYZ color space was applied. The results obtained show the influence of the different characteristics of the optoelectronic imaging sensors on the color measurements.

1. INTRODUCTION

To use an optoelectronic image capture device as an instrument for color measurements it is necessary to obtain their spectral, spatial and colorimetric characterization (Hunt 1995, Sharma 2003, Vrhel 1999). The spectral characterization consists of obtaining the spectral sensitivities and the color-matching functions for the different channels (RGB) of the device (Martínez-Verdú 2002). The spatial characterization consists of obtaining equal pixel responses of the image sensor from a flat-field of illumination (flat-field correction matrix) (Healey 1994). The color characterization of a digital image capture device consists of calculating the colorimetric profile between the RGB space of the device and the CIE-1931 XYZ standard space (Martínez-Verdú 2003).

The main problem with digital image capture devices is controlling their raw RGB space. Although the basic components are always essentially the same –zoom lens, opto-electronic sensor (CCD or CMOS) and frame grabber– there are many variables, both optical (f-number, integration time) and electronic (gain, offset, matrixing, white balancing, etc.), which can alter the true raw device RGB space. Therefore, the performance of an optoelectronic digital image capture device used for color measurements can vary as a function of the selected RGB space of the color device.

2. METHODS

Spectral characterization was obtained experimentally by measuring the optoelectronic conversion spectral functions that relate the digital response of the optoelectronic sensor to the spectral exposure level (OECSF) (Martínez-Verdú 2002). The experimental set-up used permits the control of the spectral exposure over the sensor using a daylight lamp, a monochromator with constant spectral resolution and a tele-spectroradiometer. For each spectral exposure level, the response of the digital image capture device was obtained (OECSF) (Figure 1). The OECSFs were fitted mathematically by sigmoid functions defined by four parameters (Figure 2).
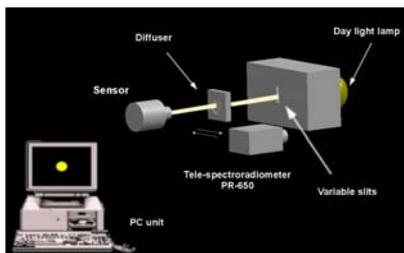
Figure 1. Experimental set-up used to obtain the OECSF.
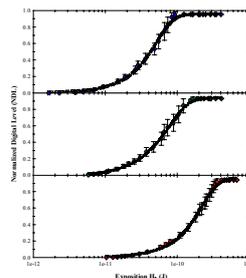
Figure 2. OECSF obtained for the channels B(450 nm), G(550 nm) and R(650 nm) using a CCD RGB camera with 3 CCD (Sony DXC-930P).

Spatial characterization was obtained experimentally correcting the response of each pixel in order to obtain an equal response when a uniform field of light was captured. To obtain an uniform field of luminance we built an integrator cube illuminated with a stabilized halogen lamp (T_c=3357K). This cube has a diffusing field of 20x20 cm where the luminance distribution was very uniform (99%). The algorithm to correct the flat-field response of the optoelectronic imaging sensor is based on calculating the gain $G(i,j)$ and offset $O(i,j)$ matrixes, from which we obtain the corrected digital level for each pixel $DL_c(i,j)$ from the initial digital level $DL(i,j)$ according to the following expression:

$$DL_c(i,j) = O(i,j) + G(i,j) \cdot DL(i,j)$$

The gain and offset matrixes can be obtained as follows:

$$G(i,j) = \frac{DL_b - DL_o}{DL_b(i,j) - DL_o(i,j)} \qquad O(i,j) = DL_o - G(i,j) \cdot DL_o(i,j)$$

where DL_b and DL_0 are the mean digital levels and $DL_b(i,j)$ and $DL_0(i,j)$ are the digital levels corresponding to the pixel (i,j) of the reference and dark image. The reference image corresponds to an image whith a mean digital level situated in the middle of the bit-depht and the dark image is the image obtained in total absence of light.

Finally, a colorimetric characterization was applied. The colorimetric characterization consists in transforming the RGB digital data into absolute tristimulus values CIE-XYZ (in cd/m^2) under variable and unknown spectroradiometric conditions. Thus, at the first stage, a gray balance was applied over the raw RGB digital data to convert them into RGB relative colorimetric values. At a second stage, an algorithm of luminance adaptation was inserted in the basic colorimetric profile. Capturing the ColorChecker chart under different light sources and comparing the estimated XYZ data to the color model developed from the measured XYZ data (in cd/m^2) using a tele-spectroradiometer, we have verified that the proposed characterization model may be broken down into two portions: first, the basic colorimetric

profile, and second, a linear correction term due only to the mismatch of the color matching functions of the camera (Martínez-Verdú 2003).

3. RESULTS

We have characterized CCD cameras with different color architectures (1 and 3 sensors) and different bit-depths (8, 10 and 12 bit) and a CMOS camera. The parameters of the devices were configured in order to obtain the raw RGB space. The normalized spectral sensitivity for the three channels RGB corresponding to two of the devices analyzed are shown in Figures 3 and 4.
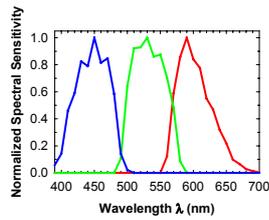
Figure 3. Relative Spectral Sensitivities corresponding to a CCD-RGB camera of 3 CCD and 8 bit-depth (SONY DXC-930P).
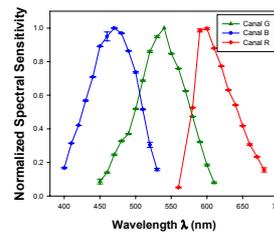
Figure 4. Spectral relative sensitivities corresponding to a CCD-RGB camera of 1 CCD and 10 bit-depth (Qimaging QICAM).

The spatial uniformity of the response to a flat field luminance improves outstandingly applying the algorithm described in the paragraph 2, as it can be seen in Figure 5, where we show the image of the flat-field of luminance captured by one of the image capture devices analyzed (Qimaging QICAM, 1 CCD, 10 bit-depth) both with and without the application of the algorithm.
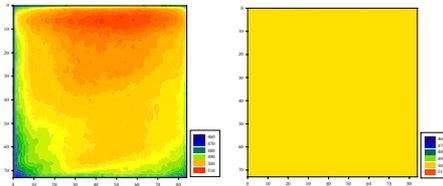
Figure 5. Image of the flat-field of luminance when the algorithm of correction is not applied (left) and when it is applied (right).

Finally the colorimetric characterization was applied to the image capturing devices analyzed. An example of a transformation of the digital levels into absolute tristimulus values CIE-XYZ (in cd/m^2) for a 3 CCD camera 8-bit depht (SONY DXC-930P) is showed in the following equation:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \mathbf{M} \cdot \left\{ \begin{bmatrix} m_R(N) & 0 & 0 \\ 0 & m_G(N) & 0 \\ 0 & 0 & m_B(N) \end{bmatrix} \cdot \begin{bmatrix} R \\ G \\ B \end{bmatrix} + \begin{bmatrix} h_R(N) \\ h_G(N) \\ h_B(N) \end{bmatrix} \right\}$$

$$\text{with} \quad \begin{cases} m_k(N) = m_{0k} + m_{1k}N + m_{2k}N^2 \\ h_k(N) = h_{0k} + h_{1k}N + h_{2k}N^2 \end{cases} , \quad k = R, G, B$$

where M is the basic colorimetric profile, m(N) and h(N) are the empirical functions describing the luminance adaptation with f-number N free and RGB triad are the colorimetric values from the gray balance applied to the original RGB digital level (DL).

In order to compare the performance of the different optoelectronic imaging capture devices analyzed, we compare color measurements obtained with these characterized devices and a tele-spectroradiometer using a standard color chart (ColorChecker Chart). The results that we have obtained until now seems to show that CCD cameras with a high level of digitalization and 3 sensor configurations have the best performance when they are used as instruments to measure color.

4. CONCLUSIONS

In this study we analyze the performance of different optoelectronic imaging sensors in order to transform image capture devices into instruments for color measurements. The main stages to characterize these devices as instruments for color measurements are the spectral and spatial characterization and the color transformation between the RGB device dependent space and a device independent space as CIE-XYZ. Spectral characterization was obtained experimentally measuring the optoelectronic conversion spectral functions. Spatial characterization was performed experimentally obtaining the flat-field correction. Finally, a colorimetric characterization was applied including a transformation between the color-matching functions of the image capture device and the color matching functions of the CIE-XYZ color space and a linear correction term to compensate the mismatch of the color matching functions of the camera. At the moment the obtained results seem to show that CCD cameras with a high level of digitalization and 3 sensor configurations have the best performance when they are used as instruments to measure color.

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Color visualization system for the discrimination of indistinguishable samples in the visible spectrum

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ABSTRACT

Samples with the same color or appearance in the visible region of the electromagnetic spectrum, which are therefore indistinguishable to the human eye, can have different properties in other parts of the spectrum. Basically, the reflectance or transmittance spectra of these samples are expected to be similar in the visible region, but can differ in other regions. In this work we present a multispectral system which uses the information included in five spectral bands of the near-infrared region of the spectrum (NIR, 800-1000 nm) in order to discriminate samples with the same appearance in the visible. The system, based on the images registered by a CCD camera, permits us to obtain falsely colored images of the samples using a color space representation which associates the camera responses of each spectral band of the near-infrared to a color channel of a calibrated device, in our case a CRT monitor. We tested different pseudo-coloring methods and principal component analysis (PCA) provided the best results in terms of color differences. The color visualization system was applied over sets of samples with identical appearance in the visible range and they could be differentiated taking into account the extra information provided by the near-infrared.

1. INTRODUCTION

In this study we use a multispectral system that works in the NIR region of the electromagnetic spectrum in order to discriminate between samples with the same appearance in the visible region. The NIR spectral range (Burns and Ciurczak 1999) can contain information related to the chemical properties of the objects being analyzed. Therefore, it can be useful to separate samples with similar color (i.e. similar reflectance or transmittance spectra in the visible region) but different composition. To achieve this, the NIR spectral information should be treated and used conveniently. These properties can be applied in several areas such as paints, the textile industry and the chemical industry.

The multispectral system used (Vilaseca, Pujol and Arjona 2004a) permits us to obtain five monochromatic images of the analyzed samples, each one corresponding to a different NIR spectral band, and combine them in order to obtain three signals which can be associated to the color channels of any calibrated device, in our case a CRT monitor, thus obtaining a pseudo-colored image of the samples (Scribner et al. 1998, Vilaseca et al. 2004b). Therefore, if two samples have different reflectance spectra in the NIR region considered, they are associated to different colors and they can be discriminated although they are identical in the visible region.

The experimental set-up used in this work consisted of a monochrome CCD camera (Photometrics Sensys KAF1400-G2) with 12-bit depth, an automated zoom lens which was

used to control the exposure over the CCD, an illumination system composed of an halogen lamp (Philips 15V 150W) used to light the analyzed samples, and five multispectral interference filters (ThermoCorion) equi-spaced in the NIR, which configured the different channels of the multispectral system. Using this configuration, the five NIR monochromatic images of the analyzed samples were obtained, and after that the pseudo-coloring methods could be applied over them in order to obtain the falsely colored image (Figure 1). The pseudo-colored image was then displayed on a calibrated CRT monitor.

a)   *b)*
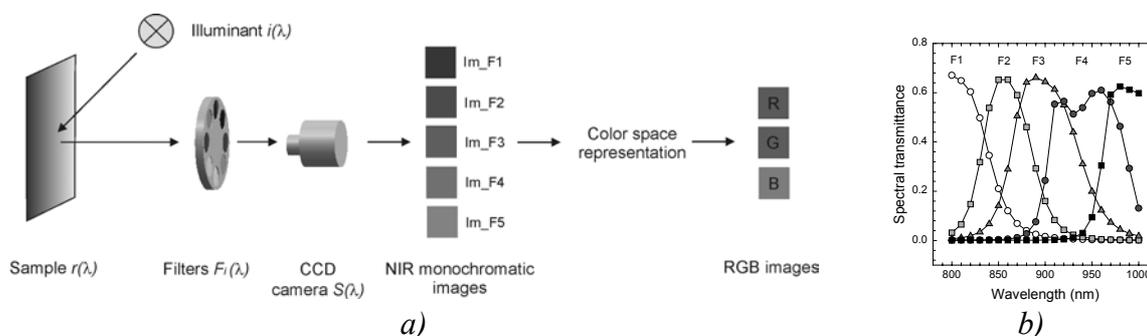
Figure 1. a) Schematic view of the multispectral system and the color visualization process.
b) Spectral transmittance of the five filters used.

2. METHOD

There are many different ways of defining a pseudo-coloring method, that is, a color space representation. Here we only describe briefly some of the methods that we have tested in previous work. We can apply pseudo-coloring methods that try to imitate the human color vision, but translated into the NIR region, or we can maximize the color differences among samples of the image in order to obtain the maximum possible discrimination. One method which works similarly to the eye is a simple linear combination, that is, we can associate the images of spectral bands corresponding to the long wavelengths with the red signal (R), the medium wavelengths to the green signal (G) and the short wavelengths to the blue signal (B). One possible combination would be for example: R = 0.5Im_F4 + ImF_5, G = Im_F3, and B = 0.5Im_F1 + ImF_2. There are other pseudo-coloring methods which better simulate the eye response in the NIR but in general the results are relatively similar to the linear combination. Other useful color space representations are based on the principal component analysis (PCA) that facilitates the colorimetric discrimination between objects and removes the present correlation of the different NIR bands. If the PCA is performed on the NIR images, we can obtain the images corresponding to the principal components of the samples being analyzed. Thus, we can associate, for example, the first principal component, which has the major part of information of the spectral reflectance of the samples, to a color palette. Therefore, each pixel of the image will have an R, G and B signal associated. We can also associate the first three principal components (V_1, V_2, V_3) to the R, G and B channels. With this kind of associations is possible to assign very different colors to samples with similar spectra in the NIR. In general with the methods that try to imitate the human color vision some spectral information of the samples will be preserved in the pseudo-colored image. Meanwhile, using the PCA based methods, this information will be lost but a higher chromatic discrimination between samples will be obtained.

3. RESULTS

The process described above was applied over two sets of textile samples with identical appearance in the visible region: one set of blue color composed of eight samples and another set of garnet color composed of seven samples (Figures 2 and 3). As it can be seen, the samples corresponding to each set have almost the same profile in the visible region, but they differ considerably in the NIR because of their different composition. However, in the visible image we can only appreciate two different appearances corresponding to the two sets, while in the NIR the samples can easily be discriminated.
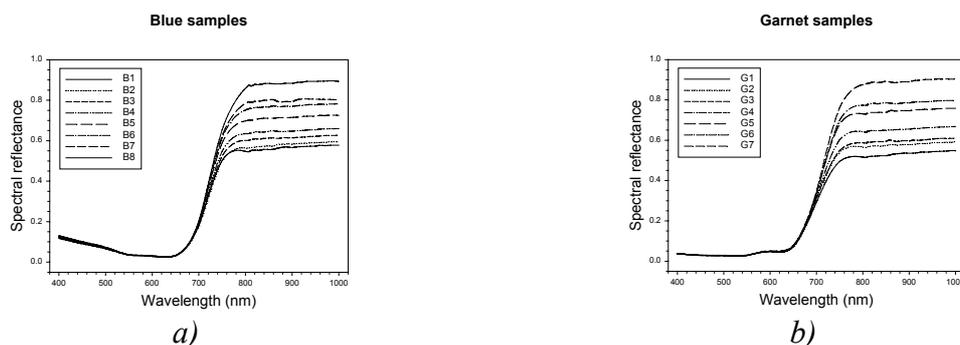
Figure 2. Spectral reflectance of the a) blue samples and b) garnet samples.
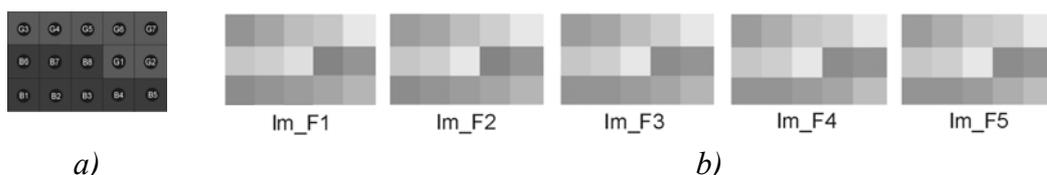
Figure 3. a) Appearance of the two sets of samples, blue and garnet, in the visible. b) The corresponding five NIR monochromatic images.

Using the five NIR images captured, the different color space representations were applied. In order to quantify the results, the CIELAB color differences between samples obtained using the different pseudo-coloring methods were measured displaying the corresponding pseudo-colored images on a conventional CRT monitor, which had been previously calibrated using a tele-spectracolorimeter (PhotoResearch PR-650). The results are summarized in Table 1. It can be seen that the results for the two sets of samples are very similar and that the method which provides the best results in terms of colorimetric discrimination is the PCA based method which uses a color palette. This method associates the different gray levels corresponding to the first principal component to a color palette, and therefore very different colors are associated to samples with different reflectance levels. On the other hand, the PCA based method which associates the three principal components to the R, G, B channels (specifically V_1-R V_2-B V_3-G) does not provide results as good as the former method. However, this method decorrelates the data better if we want to discriminate between samples with very similar reflectance spectra, because more information is used (components V2 and V3). Finally, the linear combination provides pseudo-colored images with neutral tones because of the rather constant spectral profiles of the samples in the NIR. This kind of association also allows for the discrimination between the samples, although it does not use color, but instead different gray levels.

Table 1. CIELAB color differences (mean and standard deviation) of the two sets of samples (blue and garnet) obtained using the different pseudo-coloring methods.

	CIELAB color difference	
Pseudo-coloring method	**Blue samples**	**Garnet samples**
Linear combination	13.2849 ± 8.0912	15.3196 ± 9.1105
PCA color palette	68.6495 ± 41.4166	76.0795 ± 43.8770
PCA V_1-R V_2-B V_3-G	21.0704 ± 8.92721	23.0955 ± 14.0337

4. CONCLUSION

In this study, we have presented a system for the discrimination of indistinguishable samples in the visible spectrum. The process uses a multispectral configuration which permits us to take into account the spectral information of the samples contained in the NIR range. With the five spectral bands of the system, five NIR monochromatic images are obtained and they are combined using different color space representations in order to obtain a final pseudo-colored image, which can be displayed on any calibrated device, in our case a CRT monitor. In the pseudo-colored image the indistinguishable samples appear pseudo-colored differently. In this way, the samples are discriminated. Different methods are tested and applied over two sets of textile samples with the same appearance in the visible region: methods related with the human color vision and methods which maximize the colorimetric discrimination. The PCA based methods achieve the greater CIELAB color differences between the samples.

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Four soil color charts compared in CIELAB color space

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ABSTRACT

Soil color charts, which contain standard color chips arranged following the Munsell system, are useful tools for visual assessment of soil color in the field and laboratory. Several editions of these charts, manufactured in USA and Japan, are used indifferently by soil scientists. One new and one old edition of both USA and Japanese soil color charts have been studied here in CIELAB color space, assessing the regular spread of their color chips. We plotted the loci of constant Munsell hue and chroma on the a*b* plane, and computed color differences between neighboring chips (ΔL^*, ΔC^*, ΔH^*). In the new editions, USA charts proved to have greater average lightness and chroma steps ($\Delta L^*=9.90$, $\Delta C^*=5.86$) than Japanese charts had ($\Delta L^*=8.98$, $\Delta C^*=5.36$). Irregularities in the measured values of L^* C^* h were found in the old Japanese chart with respect to the new one, including lower values of the average steps: lightness-, chroma- and hue-difference reduced by 18%, 13%, and 21%, respectively. The same trend was also found for the old USA charts, but with less reduction. It can be concluded that chips with the same Munsell notation may have different colors in different soil color charts.

1. INTRODUCTION

Soil is a loose mass of fragmented and chemically weathered rocks with an admixture of humus, which is partially decomposed organic matter. The color of a soil is a useful indicator of its composition, properties, and genesis (Bigham and Ciolkosz 1993). Moreover, color is an important distinguishing feature in most soil-classification systems (FAO 1998, Soil Survey Staff 1999). Most commonly, soil color is measured with the aid of soil color charts. This is a method widely used by soil scientists because of its quick and easy application in the field or laboratory. Soil colors are visually determined by comparing the color of a soil sample with a standard set of artificially colored papers (chips) mounted on loose cardboard pages (charts). Chips are designated by their Munsell notations and thus the soil color is specified by its Munsell hue, value, and chroma (Soil Survey Staff 1993). Specific recommendations have been made concerning the light source to be used, illuminating and viewing geometry, characteristics of the soil sample, and number of observers to standardize the color measurements in soils (Melville and Atkinson 1985, Dobos et al. 1990). However, studies on the colorimetric characteristics of different available soil color charts have not been reported.

Currently, there are two main sets of soil color charts manufactured by the Munsell Color Company (USA) and Fujihara Industry Company (Japan), respectively. Several editions of these charts have been published and are used indifferently by soil scientists. The chips in soil color charts should be systematically arranged in visual steps of equal size, the regularity of the spacing being a good indicator for the quality and suitability of soil color charts.

Our goal in this study is to evaluate the regularity in CIELAB color space of the chips from four standard soil color charts from two different manufacturers, having different use degrees.

2. MATERIAL AND METHODS

2.1 Soil Color Charts

Two standard American editions of the Munsell Soil Color Charts (Munsell Color Co. 1975, 2000) and two standard Japanese editions of the Revised Standard Soil Color Charts (Fujihara Industry Co. 1970, 2001) were analyzed spectrophotometrically. The American charts of 1975 (USA1975) and 2000 (USA2000) have 180 and 238 chips, respectively, arranged on seven hue charts: 10R, 2.5YR, 5YR, 7.5YR, 10YR, 2.5Y, and 5Y. Both the Japanese charts of 1970 (JAPAN1970) and 2001 (JAPAN2001) have 258 chips, including an additional hue chart (7.5R). The USA2000 and JAPAN2001 charts were completely new, whereas JAPAN1970 and USA1975 had been previously used for soil color measurements in the field and laboratory. Before spectrophotometric color measurements, the chips of JAPAN1970 and USA1975 were cleaned by wiping off the dirt lightly with a clean wet cloth.

2.2 Color measurements

Color measurements of all chips were performed using a Minolta CM-2600d spectrophotometer, operating with specular component excluded, and a bandwidth of 10 nm. Nine measurements (3 zones × 3 replications) were made for each color chip, and the average result was adopted for further computations. The D65 illuminant and CIE 1964 Supplementary Standard Observer were assumed for the calculation of colorimetric data in CIELAB system (CIE 1986). The repeatability (standard deviation of ten successive measurements) of our instrument for the CIELAB coordinates was lower than 0.048 units. Lightness, chroma and hue-differences between neighboring chips within each color chart were analyzed from ΔL^*, ΔC^*, and ΔH^*, the later using the Sève's equation (Sève 1991).

3. RESULTS AND DISCUSSION

We plotted in CIELAB the Munsell loci of constant hue and chroma (Figure 1). Each point on the a*b* plane was the average of the chromatic coordinates measured for the color chips with the same Munsell hue and chroma notations. So, these loci refer to the average Munsell value of the charts. According to Berns (2000), in a perfect match between the Munsell variables and CIELAB, these loci of constant hue and chroma would be a symmetrical and circular 'spider-web' plot. The chart USA2000 approaches this condition rather well (Figure 1a). The hue lines, which join dots of constant Munsell hue, are nearly straight and evenly spaced. The chroma contours, which join dots of constant Munsell chroma, are nearly circular on the a*b* diagram.

There was very little difference in how well the color chips were visually spaced in hue in USA2000 (Figure 1a) and JAPAN2001 (Figure 1b). The CIELAB hue-differences (ΔH^*) between neighboring chips at chroma /1, /2, /3, /4, /6, and /8 were 0.93, 1.68, 2.44, 3.05, 4.42, and 5.72 CIELAB units, respectively, in USA2000, and 0.88, 1.68, 2.40, 3.15, 4.51, and 5.72 CIELAB units in JAPAN2001. However, the values of ΔL^* and ΔC^* (with some exceptions at 2.5Y) were greater in USA2000 than in JAPAN2001 (Table 1). This means that the

lightness and chroma distances between new color chips depended on the manufacturer. On the average, in the Japanese charts, ΔL* values were 8.98 and ΔC* 5.36 CIELAB units, while the average values in the American charts were 9.90 and 5.86 CIELAB units, respectively.
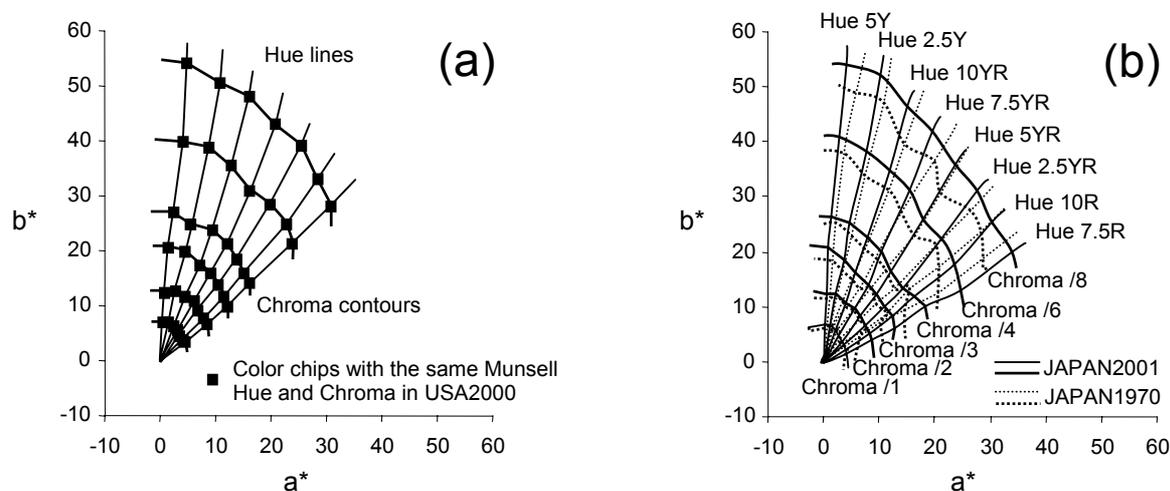
Figure 1. Loci of constant Munsell hue and chroma for American (a) and Japanese soil-color charts (b) plotted in CIELAB.

As illustrated in Figure 1b, the old charts have greater irregularities in the hue and chroma spacing. With respect to the new charts (JAPAN2001), the lines appeared deformed in the old charts (JAPAN1970). For the old charts, Munsell hue lines are unevenly spaced and Munsell chroma contours have ups and downs. The chroma contours in JAPAN1970 are below those of JAPAN2001, and the hue lines in JAPAN1970 are on the right or left of the hue lines of JAPAN2001. More specifically, it seems that yellow charts such as 5Y, 2.5Y or 10YR reddened, while red charts as 7.5R or 10R underwent a certain yellowing, and all charts faded in chroma as a consequence of the field and laboratory use.

Table 1. Average CIELAB lightness (ΔL) and chroma (ΔC*) differences for one step of Munsell value and chroma, respectively, in hue charts of different editions.*

Charts	7.5R	10R	2.5YR	5YR	7.5YR	10YR	2.5Y	5Y
JAPAN1970 ΔL*	7.45	7.19	7.07	7.02	7.62	7.41	7.57	7.73
JAPAN1970 ΔC*	4.28	4.58	4.30	4.11	4.23	4.94	5.10	5.66
USA1975 ΔL*		9.51	8.35	9.13	8.98	9.45	9.37	9.41
USA1975 ΔC*		4.89	4.90	5.43	5.31	5.80	6.31	6.14
USA2000 ΔL*		9.93	10.15	9.83	9.88	10.01	9.95	9.55
USA2000 ΔC*		5.27	5.46	5.80	5.85	6.33	5.95	6.33
JAPAN2001 ΔL*	8.64	8.95	8.82	8.90	9.20	9.06	9.12	9.14
JAPAN2001 ΔC*	4.60	4.78	4.90	5.09	5.49	5.63	6.09	6.33

Color fading over time seems to have homogenized the color gamut represented by the Japanese charts, reducing the hue, lightness, and chroma distances between neighboring chips. With respect to the new charts, hue differences (ΔH*) decreased in old charts between 0.24 (at chroma /1) and 0.80 (at chroma /6) CIELAB units, with a mean reduction of 21%. On the average, lightness and chroma distances (ΔL* and ΔC* in Table 1) also change from 8.98

and 5.36 CIELAB units in JAPAN2001 to 7.38 and 4.65, respectively, in JAPAN1970. This indicates a reduction of lightness distance by 18% and chroma distance by 13%.

Although we do not know the specific causes, color fading in American used charts was less pronounced. The average values in USA2000 were 9.90 for ΔL^* and 5.86 for ΔC^*, whereas the average values in USA1975 were 9.17 for ΔL^* and 5.54 for ΔC^*. A reduction of only 0.73 units (7%) for ΔL^*, and 0.32 units (5%) for ΔC^* occurred in USA1975.

4. CONCLUSIONS

This study shows that the steps between color chips of standard soil color charts have different size depending on their manufacturer and degree of use. For new charts, average lightness and chroma distances between nearest neighboring chips in American charts are greater than in Japanese charts by 0.92 and 0.50 CIELAB units, respectively. Comparing the average step of old and new charts, lower hue (0.80 to 0.24 CIELAB units), lightness (1.60 to 0.73 CIELAB units), and chroma (0.71 to 0.31 CIELAB units) differences were found.

We believe that the original quality of printing and the color fading over time lead to relevant color changes in standard soil color charts.

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Roselle anthocyanins as a natural food colorant and improvement of its colour stability

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ABSTRACT

Roselle anthocyanins extract solution at a pH of 2.5, 13.5°Brix, was subjected to freeze-drying. Maltodextrin and trehalose, each at 2 and 3% (w/v), were used as stabilisers in freeze-dried powder. Freeze-dried powder without a stabiliser was used as a control. During a 15-week storage period at 30°C, anthocyanins content and colour were evaluated. Addition of maltodextrin and trehalose retarded degradation of anthocyanins. The roselle powder containing 3% (w/v) maltodextrin provided superior stability over other stabilisers and was then used in a model system of a drink. During the storage, the rate of colour changes in a drink containing roselle anthocyanins extract was higher than that in drinks containing either SAN RED RC® or synthetic carmoesin. Decreases of chroma with increases of lightness were observed, while there was not much change in hue angle. The overall preference of the drinks containing either SAN RED RC® or carmoesin remained "acceptable" throughout, whereas the drink containing roselle anthocyanins extract was "not acceptable" after 56 days of storage.

1. INTRODUCTION

Colour is an important factor influencing consumers' acceptability of food products. This is due to the fact that consumers always associate food colour with other qualities such as freshness, ripeness, and food safety. Thus, many food products have added food colorants to make the products more desirable. At present, the role of anthocyanins as food colorant is becoming increasingly important. Not only do they contribute to the most important attributes of food —both for aesthetic value and for quality judgement— but also they tend to yield potential positive health effects, as they have been observed to possess potent antioxidant properties (Tsai et al. 2002). Anthocyanins are approved as food colorants (Wrolstad 2000). The use of anthocyanins may show benefits over that of synthetic colours. However, the use of these colorants in food products may face some problems due to their stability during storage caused by temperature, oxygen and light (Francis 1989).

Since roselle (*Hibiscus sabddariffa* L.) is widely grown in Thailand and tropical areas, it could be another potential source of anthocyanins as a natural food colorant. However, natural food colorants are not stable in food products. They can be decolourised and degraded during storage. This study aimed to improve colour stability of anthocyanin extracts from roselle by adding either maltodextrin or trehalose as a stabiliser. Colour stability, colour appearance and observers' colour preference of the roselle anthocyanins over a storage period of 12 weeks were quantified and compared to SAN RED RC® and synthetic carmoesin, which are commercially used as food colorants.

2. MATERIALS AND METHODS

2.1 Stability of freeze-dried anthocyanins powder during storage

Frozen roselle calyces were used as raw materials. The extract solution at a pH of 2.5, 13.5°Brix, was subjected to freeze-drying under 0.05 hPa vacuum for 15 hours. Two types of stabilisers [Maltodextrin (Maldex 100®, Abba, Thailand) and trehalose (Treha®, Hayashibara, Japan)] at a concentration of 2 and 3% (w/v) were added to the sample before freezing. Freeze-drying of the extract solution without a stabiliser was also included as a control. After freeze-drying, the dried product was ground into powder. Three grams of sample powder were separately packed into sachets (3.5 × 5 in.) made of metalised film. Each sachet was then vacuum-sealed and stored at 30°C. For each sample group, two sachets were randomly selected for analysis every week for a period of 15 weeks. Before any analysis, the powder was re-hydrated to the original volume. The samples were analysed in terms of anthocyanins content and colour.

Anthocyanins content was determined using the pH differential method (Fuleki and Francis 1968). Absorbance was measured at 517 nm with a Shimadzu UV240 spectrophotometer. Anthocyanins content was expressed in terms of relative anthocyanins.

CIE L^*, a^*, b^* values were measured with a Minolta CR-300 colorimeter, with illuminant D65 and 10° observer. Chroma $(a^{*2}+b^{*2})^{1/2}$, hue angle (arctan b^*/a^*) and total colour difference, ΔE^*, $(\Delta L^{*2}+\Delta a^{*2}+\Delta b^{*2})^{1/2}$ were calculated.

2.2 A model system of a drink

A model system of a drink with added colorants (0.1% w/v extract anthocyanins colour, 0.05% w/v SAN RED RC®, and 0.05% w/v synthetic carmoesin) was studied. The ingredients for the drink were sugar (10% w/v), citric acid (0.5% w/v) and colorant. The drink was pasteurised at 85°C for 20 minutes. Each drink was then aseptically hot filled into glass bottles (180 ml) with 1-ml headspace. Their anthocyanins content and colour were measured as described in Section 2.1. For each sample group, two bottles were randomly selected for analysis every week for a period of 12 weeks. All bottles were kept at 30°C.

For visual colour analysis, thirty observers were asked to evaluate the overall colour quality of the sample as a roselle-coloured drink and to rate it using a 9-hedonic scale from "dislike extremely" to "like extremely".

3. RESULTS AND DISCUSSIONS

3.1 Stability of freeze-dried anthocyanins powder during storage

Anthocyanins content was reported in the form of anthocyanins retention. Figure 1 shows a plot of ln (C/C$_o$) versus storage time (where C is anthocyanins content after t days of storage and C$_o$ is initial anthocyanins content) which yields a straight line. This fit for the control indicated a first order kinetic while that for the sample containing a stabiliser showed a pseudo-first order kinetic. The results showed that addition of maltodextrin and trehalose retarded anthocyanins degradation in freeze-dried powder. The half-life values of anthocyanins in control and the powder with 2 and 3% (w/v) of trehalose, and the powder with 2 and 3% (w/v) of maltodextrin were approximately 92, 120, 98, 161, 248 days, respectively. The use of 3% (w/v) maltodextrin thus provided superior stability over other

stabilisers under similar conditions. Chandra, Nair and Iezzoni (1993) also found that anthocyanins pigments, extracted from tart cherries, stored with dextrins were more stable than those without additives.

In the case of colour analysis, it was found that during the storage there were minor changes in lightness and hue for all samples. However, there were significant changes in chroma which was observed as the colour of samples gradually became duller over the storage time. The results showed that a sample with 3% (w/v) maltodextrin added had fewer changes in chroma than any other samples (Figure 2).
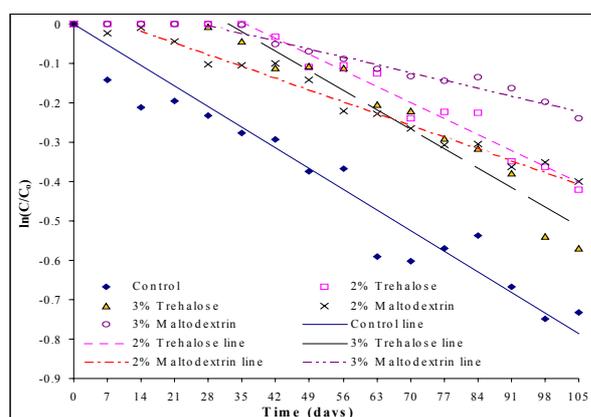
Figure 1. Degradation of anthocyanins in freeze-dried samples stored at 30°C.
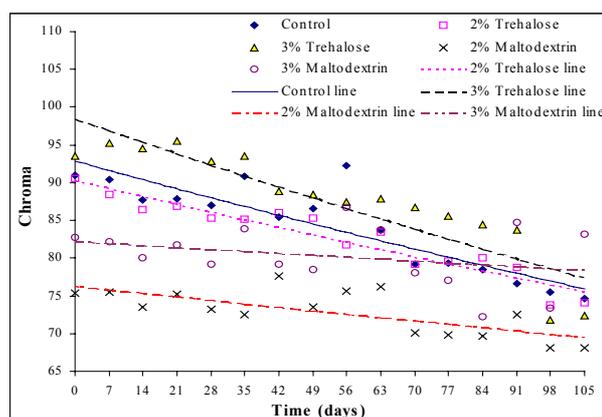
Figure 2. Changes in chroma of freeze-dried samples during storage.

The results of anthocyanin degradation and visual colour changes in this study indicated that the freeze-dried roselle powder with 3% (w/v) maltodextrin as a stabiliser appears to be reasonably stable in storage at 30°C. Thus, in a further investigation of colour stability of roselle anthocyanins in comparison with SAN RED RC® and synthetic carmoesin, the roselle powder with 3% (w/v) maltodextrin was used as colorant in a model system of a drink.

3.2 Colour measurement in a model of system of a drink

Relative anthocyanins content in the drink containing anthocyanins was calculated. Degradation of anthocyanins in the drinks followed first order reaction kinetic (Figure 3). The results showed that the decrease in anthocyanins content in the drink containing SAN RED RC® was lesser than that in the drink containing roselle anthocyanins extract.

In colour analysis, the results revealed that with increasing storage time, chroma of coloured drinks decreased, as opposed to increasing lightness, indicating that the drinks were decolourised. This was mainly because of degradation of anthocyanins or formation of polymeric colour. Despite a change in pigment concentration, any change in hue was negligible. Figure 4 shows total colour differences between non-aged (zero day) and storage-aged coloured drinks over 12 weeks. A drink containing carmoesin appeared to be reasonably stable in colour while a drink containing roselle anthocyanins extract showed the largest colour-change rate. The results obtained from visual colour analysis indicated that overall preference of the drink with roselle anthocyanins extract was not acceptable after 56 days of storage, whereas the drinks with either SAN RED RC® or carmoesin were acceptable throughout the storage of 84 days. It should, however, be noted that the non-aged drinks with roselle anthocyanins extract and SAN RED RC® were rated as "like moderately", and the drink containing carmoesin as "like slightly".
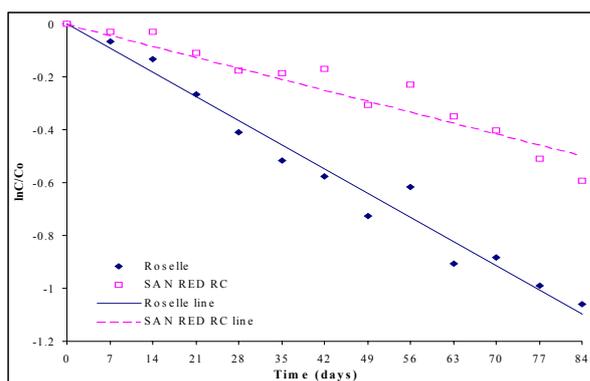
Figure 3. Degradation of anthocyanins in coloured drinks stored at 30°C.
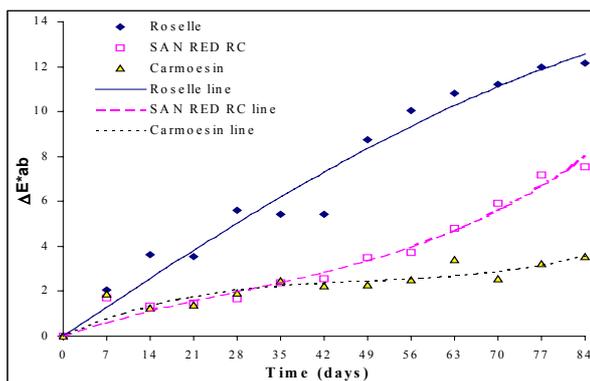
Figure 4. Colour differences of coloured drinks during storage.

4. CONCLUSIONS

Improving the colour stability of roselle anthocyanins powder by adding either trehalose or maltodextrin as a stabiliser was studied. The freeze-dried powder with 3% (w/v) maltodextrin proved to have superior colour stability. A model system of a drink adding this roselle anthocyanins powder as a colorant was carried out and the colour stability was compared to that of drinks containing commercially used colorants: SAN RED RC® and synthetic carmoesin. Although a drink with roselle anthocyanins powder was the least stable in colour, its overall preference was rated as "like moderately", which was superior to a drink containing carmoesin which had a visual score of "like slightly". In addition, the overall preference of the drink with roselle anthocyanins was acceptable over 56 days. This suggests that the roselle anthocyanins powder could be used as a natural colorant in food or beverages.

ACKNOWLEDGMENTS

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Gamut characteristics of chromatic and identical desaturated achromatic reproductions

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ABSTRACT

An important number of parameters define the quality and fidelity of graphic imprints; among them many are gamut related or gamut influenced. Purpose of the research was to define influences that different combinations of rendering methods have on the chromatic and identical desaturated (achromatic) originals, seen as a function of transferring and gamut mapping in reproduction process and various starting color spaces used in graphic technology.

1. INTRODUCTION

Because of the nature of the graphic reproduction process the gamut of original (scanner pattern or the digital camera scene) is, as a rule, always greater that the gamut of the four-color prints. However, because of the psychophysiology of our perception, the non-linearity of the human visual system enables the four-color (CMYK) print to be treated as the substitutionally very acceptable presentation of the original. The difference between the gamut (of the original and of the print) exists and it is possible to measure it instrumentally and to present it. However, the question arises concerning the difference in quality experience for the contents of the identical reproduction which are produced in the same way (on the same digital printing machine, with the same transforming method – rendering method and from the identical starting color space), i.e. with the identical gamuts, but different chromatic and achromatic atmosphere.

In the contents of the above mentioned, this work is directed primarily to visual evaluation of the quality experience of prints, for the identical reproduction processes and their correlation with the calculated gamut volumes, with the aim to contribute to the solution for the determined problems of the chromatic reproduction and their identical desaturated (achromatic) ones in the digital printing, respectively, the solutions which will give good results in the defined ratio of conditions (for the given starting color space and the rendering method). Such solutions can be universal in the determined sense and they can be accepted as the standard.

2. EXPERIMENTAL

In accordance to the research aims, the designed research aims, the test form presented in Figure 1 was designed. The left part of the form is made from three chromatic pictures in the unchanged size and it is intended for visual evaluation. The middle part is the ECI measuring form consisting of 210 patches of different combinations of color values of the subtractive synthesis, generated by the vector graphics in the steps of 5%. The right part was formed by the complete desaturation of the left part with the identical contents. Although it is achromatic in experience, it is generated in printing with all four colors of the subtractive synthesis. It is

also intended for the visual evaluation. In printing, each test form is entered in three starting color spaces (RGB, CMYK, L*a*b*) and rendered with each of the defined standard methods: perceptual one, saturation method, relative colorimetric method and absolute colorimetric one. 24 different samples were obtained by the mentioned process (3 color spaces × 4 rendering methods × 2 digital printing machines). Manifold glossy fine art paper coated on both sides with the high whiteness degree (L*=95.8, a*=0.2, b*=0.3) with the grammage 135 g/m^2 was used as the printing substrate. Before the printing process the paper was conditioned in the period of 48 hours, on the standard environmental conditions. The edition of each sample was 10 prints (because of the statistic accuracy during the measuring process).

Figure 1. Presentation of the test form used in the investigation.

Measuring of samples (ECI form) was performed on X-Rite DTP 41 reflection spectrophotometer, with the range of the wave lengths is from 390 to 710 nm, steps of 10 nm and the illumination geometry of 45°/0°). The accuracy of the device, i.e. the average aberration in the sense of reflection was mostly up to 0.5% by the wavelength step. The visual evaluation was performed on the sample of 22 examinees (12 females and males) with the average age of 23 years in the defined and standardized environmental conditions, in accordance with the guidelines of the CIE TC 1-27 norm from 1994 (the illumination of the room with standard light source D50, and neutral light gray curtain in the background). The distance between the samples and the examinees was in the range of 75 to 100 cm. The evaluation time of the original and the reproduction was not limited. The viewing direction was not strictly defined. The technique of the visual evaluation which was the basis for sample analysis was *simultaneous binocular*. At the mentioned technique, during the evaluation, the original and the reproduction were placed one next to the other in the whole visible area at the same time, i.e. the evaluation was done by the simultaneous comparison of the original and the reproduction. Three separate investigations were performed, separately for chromatic samples and separately for achromatic samples in order to distinguish how much the identically made achromatic and chromatic samples with the identical gamuts, influence the experience of the observers, so that he can evaluate some sample as better or worse.

The *first* visual investigation was based on the selection of the best print towards the worst one with regard to the different rendering methods in particular color space. During evaluation, the observer chooses the best sample, then the second best, then the third one and finally the fourth one among the four different prints obtained by the different rendering methods (perceptual, saturation, relative and absolute colorimetric one) in regard to the starting color space. The best sample, according to his subjective experience, gets the mark 4

and the last one gets the mark 1. The aim of such visual evaluation is to determine the influence of particular rendering method for steady color space on the total experience of the print quality.

The *second* visual investigation was based on the selection of the best print towards the worst one with regard to the different color spaces (RGB, CMYK and L*a*b*) for the given rendering method. During evaluation, the observer chooses the best sample, then the second best, then the third one among the three different prints obtained for each starting color spaces in regard to particular rendering method. The best sample, according to his subjective experience, gets the mark 3 and the last one gets the mark 1.

The *third* visual investigations was based on the selection of the best print of particular rendering method in regard to the presentation of separate reference original on the computer screen for the given color space. During evaluation, the observer chooses the best sample, then the second best, then the third one and finally the fourth one, among the four different prints obtained by the different rendering methods for each color space, comparing them with the original on the computer screen. The best sample gets the mark 4 and the last one gets the mark 1. The aim of such visual evaluation is to determine the influence of the original presented on the computer screen in the given color space for different particular rendering methods on the total experience of the print quality.

3. RESULTS

The results of the instrumental analysis, i.e. calculation of the gamut volume, are presented in Table 1, and the results of the visual evaluation are presented in Table 2, but only for *first* and *third* evaluation (the results of the *second* evaluation have not shown correlation with others).

*Table 1. Presentation of the gamut volume (CIE L*a*b* CCU) of the individual samples.*

Starting color space	Rendering method	Kind of toner	Volume of gamut
RGB	saturation	dry	792887
CMYK	saturation	dry	756073
Lab	saturation	dry	728200
RGB	saturation	liquid	467058
CMYK	saturation	liquid	401812
Lab	saturation	liquid	297116
RGB	relative colorimetric	dry	965570
CMYK	relative colorimetric	dry	838543
Lab	relative colorimetric	dry	830160
RGB	relative colorimetric	liquid	593611
CMYK	relative colorimetric	liquid	553525
Lab	relative colorimetric	liquid	419210
RGB	perceptual	dry	791049
CMYK	perceptual	dry	751777
Lab	perceptual	dry	738192
RGB	perceptual	liquid	465158
CMYK	perceptual	liquid	396992
Lab	perceptual	liquid	293928
RGB	absolute colorimetric	dry	1038538
CMYK	absolute colorimetric	dry	859160
Lab	absolute colorimetric	dry	849975
RGB	absolute colorimetric	liquid	682203
CMYK	absolute colorimetric	liquid	578016
Lab	absolute colorimetric	liquid	587851

Table 2. Average visual evaluation marks for the first and the third visual investigation.

Color space / Kind of toner	Type of reproduction	FIRST VISUAL EVALUATION				THIRD VISUAL EVALUATION			
		Rendering method				Rendering method			
		P	S	RC	AC	P	S	RC	AC
RGB / Dry	chromatic	2,0	2,4	3,0	2,5	2,1	1,8	3,3	2,8
	achromatic	1,2	2,4	2,7	3,7	1,9	1,7	2,7	3,7
RGB / Liquid	chromatic	1,3	1,7	3,0	3,9	1,4	1,6	3,2	3,4
	achromatic	1,6	1,4	3,2	3,8	1,8	1,5	3,3	3,4
CMYK / Dry	chromatic	2,0	2,9	2,8	2,9	2,4	3,2	2,4	2,0
	achromatic	2,9	2,9	2,3	2,4	1,9	3,0	3,0	2,1
CMYK Liquid	chromatic	1,9	1,9	2,9	3,3	1,5	1,7	3,8	3,0
	achromatic	2,1	1,5	3,7	2,9	1,9	1,8	3,8	2,5
L*a*b* / Dry	chromatic	1,5	2,5	3,0	2,9	2,0	2,0	3,0	3,1
	achromatic	1,5	2,2	3,1	3,2	1,8	1,2	3,5	3,5
L*a*b* / Liquid	chromatic	1,2	1,6	3,2	3,5	1,4	1,8	3,1	3,7
	achromatic	1,4	2,0	3,7	2,9	1,8	1,7	3,3	3,1

4. DISCUSSION AND CONCLUSION

It was proved that for each individual rendering method, the greatest gamut volume on the reproduction was obtained by using the RGB starting color space of the original, followed by CMYK and the smallest one was obtained by using the L*a*b* color space, if the relation of the gamut size and the applied rendering method is observed. The greatest gamut volume is obtained by using the colorimetric rendering methods, followed by the saturation method and finally by the perceptual one.

The results of the visual evaluation of achromatic and chromatic reproductions with regard to the influence of particular rendering method for the steady color space on the total quality experience, show similar trends in the mark size as well as the mutual relations with regard to the applied rendering method on both print types. The best results, i.e. the highest marks were obtained by applying the colorimetric rendering methods, while the considerably lower ones were given to the prints generated by perceptual and saturation method. In regard to the different starting color spaces of achromatic and chromatic reproduction, there is a certain similarity, i.e. the relation in the height of the marks for particular color space is retained but the relation among the different color spaces was not retained.

One of the most interesting and perhaps the most important facts is, that although the marks are not identical, almost identical mutual relationship of the given marks obtained by the first phase of the visual investigations (without the possibility of comparison with the reference original) and the third phase of the visual evaluation (where each sample could be compared with the reference original on the computer screen) for different rendering methods was retained.

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The permanence of conventional and digital offset prints

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ABSTRACT

The permanence of prints depends of its components and of the influence of the external factors. The test form used in printing was designed from the standard patterns composed of 210 patches of different combinations of subtractive synthesis color values, generated by vector graphics in the steps of 5%. The changes of the print gamut can be seen in relation with the printing technique, composition of ink and the time of print ageing. The changes occurring as the result of accelerated and natural ageing of prints in relation to the optical stability of prints have been discussed in the paper.

1. INTRODUCTION

Deterioration in quality of an aged paper or prints can manifest itself in chemical permanence and the decrease in mechanical durability. The permanence of paper depends on the chemical resistance of its components and of the influence of external factors. Paper permanence includes such things as lightfastness and refers to the ability of printing inks to resist fading or changing of color upon exposure to light or weather (Gurnagual et al. 1993).

In regard to the changes of paper over time, the terms durability is also interesting. Paper durability depends on the physical mechanical properties of raw materials used in paper production (fibers, sizing agent, additives, fillers) as well as on environment elements such as microclimatic conditions (heat, humidity, light), pollutants present in the air (ozone, oxides of sulphur and nitrogen), traces of transition metal ions (Fe (III), Cr (III), Cu (II)), biological agents (micro-organisms, mould) and printing processes (composition and kinds of inks) (Bukovsky 2000, Johansson 2000, Porck 2000, Lee, Bogaard and Feller 1989).

Discoloration of a paper may be caused by the formation of chromophores upon ageing as a result of exposure to among other light and volatile gases. Many volatile compounds as well as alcohols, ketones, aldehydes, carboxylic acids, aromatic and aliphatic hydrocarbons and eters can be released from paper during degradation processes depending upon paper chemical compositions (Carter, Begin and Grattan 2000, Bulow et al. 2000).

Only one segment of the extensive researches referring to the comparative three-dimensional and two-dimensional presentation of gamut of prints aged in different periods is presented in this paper. The influence of the natural and accelerated ageing of prints on their optical stability has also been discussed.

2. EXPERIMENTAL

Color prints made on the digital offset printing machine Indigo E-Print 1000+ and on the conventional printing machine Heidelberg are used in the researches. Test form has been designed by using the standard ISO and ECI patterns. It has been created in Adobe Photoshop application. The part presenting the ECI measuring segment consists of 210 patches of

different combinations of color values of the subtractive analysis, generated by the vector graphics in steps of 5%.

The coated paper with the grade of whiteness expressed in CIE L*a*b* values: L* 94.0, a* 0.21 and b* −0.61 has been used in printing. The grammage of the printing surface is 115 gm^{-2}.

After the printing the prints were differently treated before the further analyses. Based on that they were divided in three series: not aged prints, accelerated aged prints and natural aged prints. For accelerated ageing, the climate chamber was used with the following conditions: temperature 80 °C, humidity 65%, without radiation.

For measuring the three-stimulus values X-Rite DTP 41 spectrophotometers with the illumination geometry of 45°/0° was used. The measured values of the determined print series for each 210 patch were expressed in CIE XYZ values. From the middle values CIE XYZ, by using the application Color Open, the values CIE L*a*b* were obtained in order to enable the construction of gamut of the described series samples in the three-dimensional unified space.

3. RESULTS AND DISCUSSION

With the aim to explain and define the relations bound to the gamut, describing the properties of different reproduction are presented in 2D and 3D graphs. Three-dimensional and two-dimensional presentation of gamut of the conventional offset print, conventional offset print with the modeled ink with greater ratio of renewable raw material and of digital offset print has been presented in Figure 1.
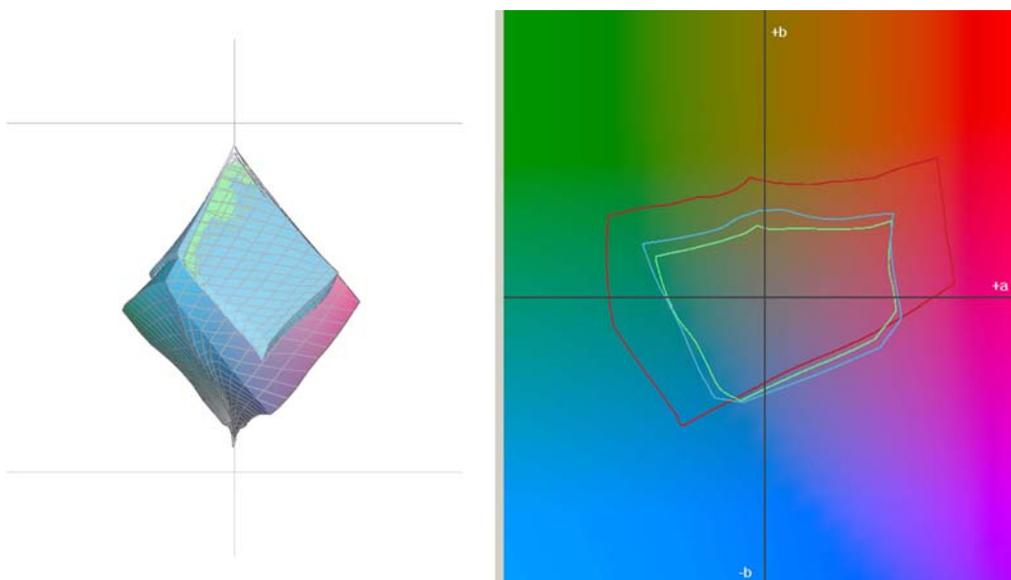
Figure 1. Three-dimensional and two-dimensional presentation of print gamut of different printing techniques and of different composition of the offset ink.

The difference in gamut size in relation to the different printing techniques (the greatest gamut for the digital offset print) is visible from the results. Considerably smaller difference was noticed in relation to the composition of the offset ink (the increase of the ratio of the renewable raw material – smaller value decrease in green-orange).

In Figure 2 the comparative 3D and 2D presentations of gamut of digital offset prints before and after accelerated ageing are given.

Accelerated ageing, 10 days

Accelerated ageing, 30 days

Accelerated aged

Natural aged
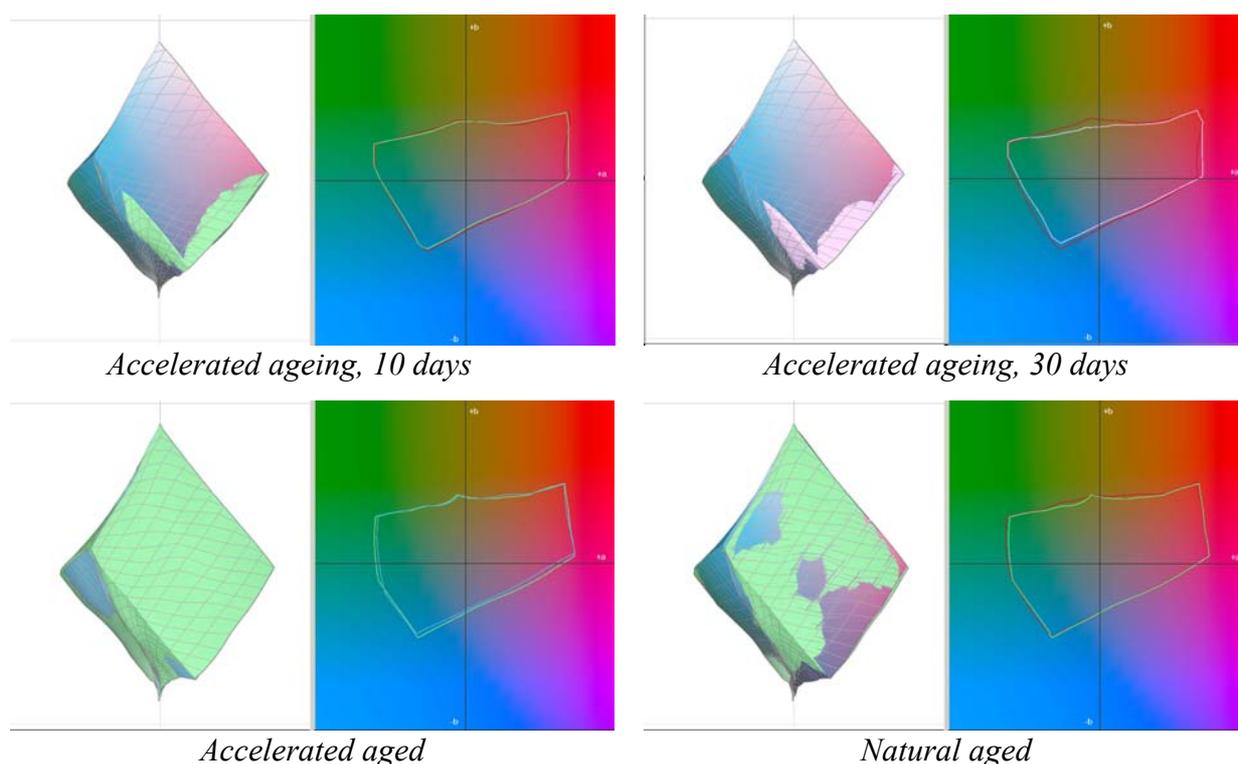
Figure 2. Three-dimensional and two-dimensional presentation of gamut of prints in relation to the ageing conditions of the digital prints.

The presentations of gamut in all the cases refer to the value L* 50. As it is visible from the results, the accelerated ageing of digital prints in the period of 10 days, under previously described conditions, has almost no influence on the change of the gamut of prints. However the increased ageing periods (30 days) cause the reduced value increase in yellow and blue area.

Comparing the three-dimensional and the two-dimensional gamut presentation of accelerated aged prints one can notice the reduced increase in the purple field in relation to the natural aged print.

The reactions caused by the process of the accelerated ageing or natural ageing of prints, influencing the changes of the printing substrate characteristics or the pigment in the composition of ElectroInk can be the cause for that.

Table 1 presents the values L*a*b* for the printing substrate in dependence on the ageing conditions.

*Table 1. L*a*b* values of the printing substrate.*

Sample	L*	a*	b*
non aged	94.0	0.21	−0.61
accelerated aged	93.0	0.09	2.99
natural aged	93.6	0.07	1.82

Not only the changes in lightness-darkness can be observed in ageing of prints, but also shifts in red-green and yellow-blue co-ordinates of the printing substrate. However, one could say that somewhat more considerable change is in the increase of b* (increase in yellow chromophores).

Generally, based on the chemical and physical analysis of natural and accelerated aged samples have been proposed reactions such as: oxidation, acid catalyzed hydrolysis and cross-linking. In oxidation disintegration of the low molecule part of the carbon hydrates, the carbonyl groups appear which influence the decrease of lightness. The described change appears easily because of the print emanation under the influence of the light (natural ageing of prints) but also without the influence of light under the increased temperature and relative humidity of the air (accelerated ageing of prints). The new oxidation products are formed, which under the determined conditions accelerate the further disintegration and decrease additionally the optical properties.

4. CONCLUSION

Based on the investigation results, it can be concluded that smaller gamut changes of prints can be noticed in exposing the prints to longer time of accelerated ageing in the frame of the described experiments. By accelerated ageing of digital offset prints the smaller increase in purple in relation to the natural aged print has been proved. Apart from that the changes in lightness and shift in red-green and yellow-green coordinates of the printing substrate have been noticed. Such results are attributed to the oxidation reactions caused by natural ageing and even more by accelerated ageing.

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Colorimetric investigations as quality criteria of the work of art reproductions

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ABSTRACT

The quality of the work of art reproduction has been observed from the point of view of aesthetic and technological criteria. Technological criteria are composed of processes, systems and materials, which are used in the reproduction process. Aesthetic criteria include formal/methodological characteristics on which the visually presentable systems are based. The visually presentable systems represent art and technical achievements of the historical periods of the visual arts. There is the intention in this work to study the reproduction of the artwork of particular visually presentable systems by taking into consideration the aesthetic and technological characteristics. The methods comprise the visual evaluation and instrumental measurements of the reproductions to be obtained. There is the intention to determine the quality criteria of the reproduction of particular visually presentable systems by colorimetric investigations of the color characteristics.

1. INTRODUCTION

The reproduction quality of the work of art can be observed from certain aesthetic and technological criteria. *Technological criteria* are made from the processes, systems and materials used in the reproduction process. Through the interdependence of the reproduction process parameters, the conditions are formed for achieving the reproduction quality from the technological point of view. *Aesthetic criteria* comprise formal/methodological characteristics on which the visual presentable systems are based. They represent the products of the visual and technical abilities in interpretation of the visual form. *Visually presentable systems* represent the combination of visual and structural elements, by successive or simultaneous arrangement; the new basis for articulation of visual presentation is formed. The structural elements of the visual form are: point, line, plane, volume and color. In two-dimensional media the volume is presented by the continuous tonality, *valeur*. Based of the structural elements, visually presentable systems are defined as the linear ones, one-dimensional, tonal and colorist. In literature, bright-shadow is mentioned as separate visually presentable system.

Tonal visually presentable system represents tonality of one color in gradually bright-shadow tones. The brightness presents the third dimension, the depth. Structural elements (tone or brightness) are under the human eye possibility of registering. They are registered simultaneously. This visually presentable system is typical for the Renaissance period. The period of baroque is characterized by dynamics and rhythm. *Bright-shadow visually presentable system* contributes to these aesthetic laws. It represents the combination of one-dimensional and tonal system. The tone system is limited to the very narrow area and it is presented as *sfumato*. Bright-shadow visually presentable system incorporates the exposed and the unexposed parts of individually separated forms, independently on the term meaning. Term meaning of bright and shadow tends towards the rhythm strengthening (Wölfflin 1998). *Colorist visually presentable system* is the newest system of the systematically monitoring of

the visual form. Its appearance is combined with impressionism, although analogue examples existed earlier. This system is based on cold-warm dynamics of colors. Mutual relation of colors visually presents the conflict which primary explains the space and secondary the local tone (Itten 2002).

2. PROBLEM STATEMENTS

By analysis of the visually presentable systems, it is visible that it is necessary to define particular criteria for the quality of their reproductions. Each criterion has to satisfy the technological as well as the formal/methodological lawfulness. The reproductions can be evaluated objectively by the instrumental measuring methods. However, the reproduction confirms its authenticity primarily by the experience of the observer. Visual evaluation presents the subjective experience, which cannot be objectively measured. Aesthetic and formal criteria of the visually presentable system are different. Based on that, it is necessary to acknowledge them with the corresponding reproduction process. By the synthesis of subjective and objective indicators, it is possible to define particular criteria for each visually presentable system.

3. EXPERIMENTAL

Three paintings from the same author from the cycles *Split miniatures* were used as the investigated samples. The paintings were made in the oil on canvas technique and they have the same size (29 × 23 cm). Each of them belongs to one of the visually presentable systems.

Image capture with camera was performed during daylight, noon sunlight on a clear day with color temperature. The conventional camera Nikon F90X was used with Fuji Provia 100ISO 35 mm slide film processed by E-6. The developed film was scanned on TOPAZ II Heidelberg flatbed scanner with resolution of 2640 dpi, on the size 18.2 ×14.3 cm. The obtained digital data about the works of art have been processed in Adobe Photoshop 7 program. The reproductions were printed in digital technique on the machine INDIGO PRO+ on white glossy paper, 250 g/m^2. In this way three reproductions were obtained.

3.1 The methods for reproduction quality evaluation

As it was said above, the criteria have to enclose subjective and objective evaluation. The method of visual evaluation was chosen for the subjective judgment. The instrumental spectrophotometer method was chosen for the objective evaluation of reproductions.

The aim of visual evaluation was to determine how much the reproduction deviates from the original, based on the attached criteria for each visually presentable system. The criteria have been set in accordance to the formal/methodological characteristics of particular visually presentable systems, presented in Table 1. The examinees could answer the questions with: very good, good and bad. 68 persons took part in the visual evaluation: 34 men and 34 women. The competent persons, who were by their profession visual artists, visual critics and historians of art, were chosen as observers. The visual evaluation was done in accordance to the conditions determined by ISO 3664 standard (Brozovic at al. 2004).

The artworks were image captured together with the control strip under the same conditions in a short period. The control strip was used in the instrumental method for analysis of colorist values of reproductions in relation to the work of arts. Spectrophotometer

method was performed by measuring the reflection factor of the solid patches of color on the control strip. Technological process of the production of all reproductions was the same. Because of that, the middle value obtained on all three reproductions was taken as the measuring result. The measured values were made in CIE LAB color space (Wyszecki and Stiles 1982).

4. INVESTIGATION RESULTS AND DISCUSSION

The results of visual evaluation of the observers were presented by the answers of the examinees on the attached criteria, by the evaluation percentage in Table 1.

Table 1. Results of the visual evaluation.

Tonal visually presentable system:		
How is the dominant tone of the picture reproduced?	Very good 63.24%	(24 women; 19 men)
How is the brightness range of the picture reproduced?	Good 72.06%	(26 women; 23 men)
How are the bright and shadow parts of the picture visible on the reproduction?	Good 73.53%	(27 women; 23 men)
Bright-shadow visually presentable system:		
How are the dominant tones of the picture reproduced?	Very good 57.36%	(22 women; 17 men)
How is the brightness range in the dark and the bright parts of the picture reproduced?	Good 75%	(27 women; 24 men)
How is the grading between the dark and bright parts of the picture visible?	Good 66.18%	(25 women; 20 men)
How is the contrast on the reproduction achieved, by means of the difference in brightness of the brihgt and the dark parts of the picture?	Very good 67.64%	(25 women; 21 men)
Coloristic visually presentable system:		
How are the dominant tones of the picture reproduced?	Very good 55.89%	(21 women; 17 men)
How are the complementary color of the picture reproduced?	Good 80.89%	(29 women; 26 men)
How is the space relationship achieved on the reproduction by warm-cold color?	Good 76.47%	(27 women; 25 men)
How is the picture contrast reproduced?	Very good 70.59%	(26 women; 22 men)

Based on the visual evaluation of the observers, according to the mentioned criteria (Table 1), it is visible that the reproduction of tones of color was better evaluated than the reproduction of the color brightness in tonal visually presentable system and in the bright-shadow visually presentable system. In colorist visually presentable system the criterion of color tone is primary and that is the reason for the worse evaluation than in other systems. The evaluations of picture contrast show good reproduction of all the systems.

The results of the instrumental spectrophotometer measurements are presented in dependence on the total difference of colors ΔE^*_{94} in relation to the lightness change ΔL^*, chrome ΔC^* and hue ΔH^* (Figure 1).

As the values of $\Delta E^*_{94} \leq 3.0$ have been considered as the threshold of acceptability, it is visible that almost all the colors are reproduced within the acceptable boundaries. Only magenta and violet are on the boundaries of acceptability. Comparing the changes of the color lightness ΔL^* and the total color difference ΔE^* (Figure 1a) one can notice the increase of color lightness. The lightness is decreased only in red and yellow colors, which are the lightest ones of all the observed colors. The change of chrome ΔC^* (Figure 1b) is present in

all the colors. It is considerably decreased in relation to the works of art. The change of hue ΔH* (Figure 1c) is present in majority of colors but to lesser degree.
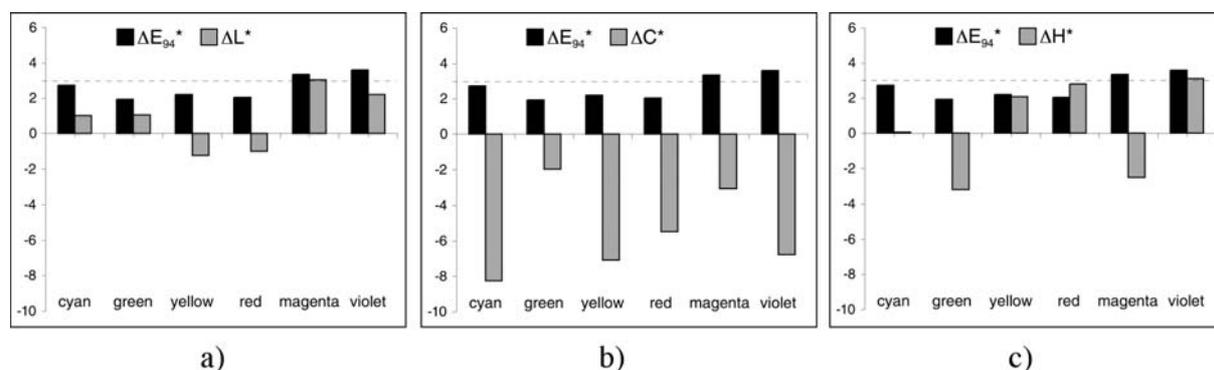
Figure 1. Relation of the total color difference ΔE* according to the change of
a) lightness ΔL*; b) chrome ΔC*; c) hue ΔH*.

5. CONCLUSION

The evaluations of the reproduction by visual judgment of the observers have shown the better reproduction of tones of colors than of color brightness. The results of the spectrophotometer analysis have shown that the color reproduction was influenced by all the observed colorist values of colors.

On the basis of the investigation results obtained by subjective and objective methods, the criteria can be defined which are necessary for the quality reproduction of the works of art according to visually presentable systems.

Tonal visually presentable system: It is necessary to reproduce correctly the lightness as the colorist characteristic of colors, while the hue and chrome are the secondary values.

Bright-shadow visually presentable system: The reproduction of lightness is primary, especially in bright and dark areas of the picture. Except the lightness, the reproduction of contrast is important. Hue and chrome present the secondary factor.

Colorist visually presentable system: The reproduction of hue is primary, especially of complementary colors as well as the chrome of colors. The values of lightness do not present an important factor as the space relation is obtained by the dynamic values of colors.

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Studies on ultraviolet-rays blocking by dyed fabrics: Comparison between direct dye/cellulose and disperse dye/polyester

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ABSTRACT

The mechanisms of UV-blocking with dye on the fabric substrates were discussed on direct dye on the cotton and disperse dye on the polyester. Cellulose and polyester films were used as model substrates of fabric, avoid of different factors of fabric such as yarn thickness, yarn count, and fabric structure and so on. Two kinds of red dyes alike in hue, C.I. Direct Red 23 and C.I. Disperse Red 1, were used. UV-blocking efficiencies of dyes and film substrates were examined on transmittance (%) of UVA-rays and UVB-rays, and UPF namely Ultra-rays Protecting Factor of skin.

1. INTRODUCTION

As decrease of stratospheric ozone layer might effect on the human health, protecting our bodies from harmful UV-rays would be very important. Blocking property against UV-rays by fabric would greatly depend on the functions of fiber kinds; yarn count and construction of fabric and dye. If some kind of UV-rays absorbers such as dye could be applied on the fabric, the blocking against UV-rays with fabric could be increase.

In previous studies, the authors studied the mechanism of UV-rays blocking by colored cotton and polyester fabrics dyed with direct and disperse dyes respectively (Mima and Sato 2000, 2002). As the cotton and polyester fabrics were different from the construction parameters of fabric (yarn count, cover factor, thickness and porosity), it is difficult to explain exactly the effects of UV-rays blocking of dye added on the fabric by dyeing. So, cellulose and polyester films were used as model substrates of fabric, avoid of different factors of fabric such as yarn thickness, yarn count, fabric structure, and so on.

2. MATERIALS AND METHODS

2.1 Films and dye materials

Cellulose film (thickness: 0.02 mm, weight: 0.002 g/cm^2) and polyester film (thickness: 0.025 mm, weight: 0.0039 g/cm^2) were used for the substrate of dyeing. Two kinds of red dyes alike in hue, C.I. Direct Red 23 and C.I. Disperse Red 1 were used. These dyes were the same as used in the previous study (Mima and Sato 2002) and have high molar absorption coefficient at the region of UVB respectively. Twelve and half pieces of cellulose film and eighteen pieces of polyester film each sized of 4×6 cm^2 were respectively dyed in the 85.4 ml and 50.4 ml of dyeing baths, that is to say, the same liquor ratio. Their bathes were controlled with different four levels of molar concentration of dye from 0.02 to 0.5×10^{-4} mol/l for cellulose

and from 0.2 to 4.0×10^{-4} mol/l for polyester. The dyed films resulted in the colors from light to deep shade in these dyeing conditions.

2.2 Measurement of dye uptake on the film and spectral transmittance of dyed film

The dye uptake (mol/g film) was quantitatively determined by absorption method using before and after dyeing bath. Non-dyed and dyed films were measured on the spectral transmittance on the wavelength from 200 nm to 800 nm using UV-VIS-NIR Spectrophotometer UV-3150 (SHIMADZU). Controlling with piling numbers of sheet, cellulose and polyester film layers were equalized the thickness of four levels, 0.1, 0.2, 0.25 and 0.4 mm thickness.

2.3 Evaluation of UV-blocking property

UV-blocking property of the film substrate and dye were examined using two methods. The one was the UV-blocking efficiency (%) calculated by transmittance curves in the region of UVA (320-400 nm), UVB (280-320 nm) and UVT of total, and the other was the UPF (ultraviolet protection factor). UPF of films were calculated according to the Australian/New Zealand Standard (*Sun protective clothing evaluation and classification*, AS/NZ 4399).

3. RESULTS AND DISCUSSION

3.1 Relation between dye uptake on the film and transmittance of a sheet of film

Table 1. Properties of dyed films and transmittance.

Sample	Degree of exhaustion(%)	Dye uptake 10^{-6}mol/g film	Y (%)	Transmittance(%)		
				UVA	UVB	UVT
Non dyeing cellulose film			89.7	89.5	85.2	88.1
Direct Red23(2)(pale shade)	98.5	2.3	87.6	88.8	84.8	87.5
Direct Red23(4)(Pale shade)	**98.5**	**11.5**	**80.7**	**86.8**	**78.4**	**83.8**
Direct Red23(5)(Medium shade)	93.8	23.3	75.6	88.4	76.5	81.7
Direct Red23(6)(Deep shade)	94.0	55.1	62.9	78.2	64.1	73.4
Non dyeing polyester film			87.5	83.2	12.2	55.3
Disperse Red1(1)(Pale shade)	95.8	0.6	73.7	78.3	10.9	54.7
Disperse Red1(2)(pale shade)	99.3	1.5	55.2	70.6	8.8	49.1
Disperse Red1(3)(Midium shade)	99.7	6.0	44.4	64.2	7.4	44.6
Disperse Red1(4)(Deep shade)	**100.0**	**12.0**	**38.4**	**56.0**	**5.4**	**38.8**

Table 1 shows dye uptake on the film, degree of exhaustion, Y (luminous reflectance) and transmittance of a sheet of dyed film. Lower the dye uptake than the cellulose films, the polyester films dyed with Disperse Red 1 have lower luminous reflectance (Y) and lower transmittance than the cellulose films dyed with Direct Red 23. That is to say, the polyester film dyed with disperse Red 1 have high UV-blocking efficiency. The transmittance of dyed films decreased with increasing of dye uptake on the film.

3.2 Effect of the dye concentration on the UV-transmittance and UV-blocking property

Figure 1 shows the spectral transmittance curves of cellulose and polyester films by example of a thickness of 0.1 mm respectively. Non-dyed polyester film itself shows considerably low transmittance at UVB region compared with non-dyed cellulose film. The UV-transmittance of dyed films decreased with increasing of dyeing concentration because of high absorption by dye on the film. The numbers in bracket indicate dyeing conditions.
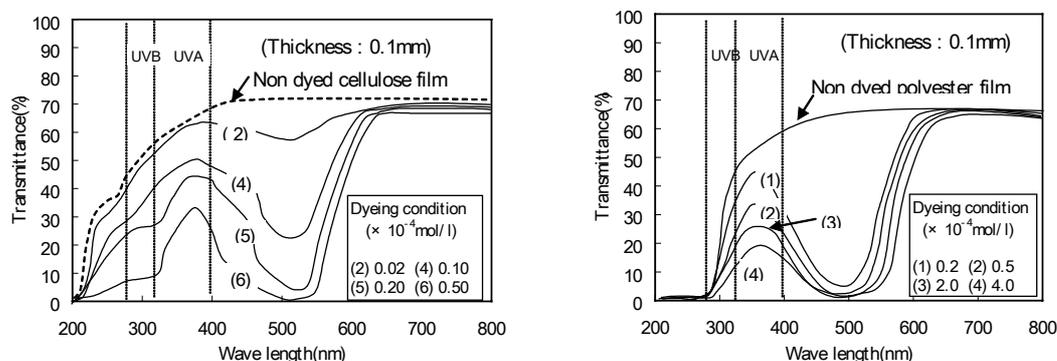
Figure 1. Spectral transmittance curve (left figure: cellulose; right figure: polyester).

3.3 Effect of piling of film on the UV-transmittance

Figure 2 shows the relations between the thickness and the transmittance of dyed films on the UVA region in the left and on the UVB region in the right respectively.
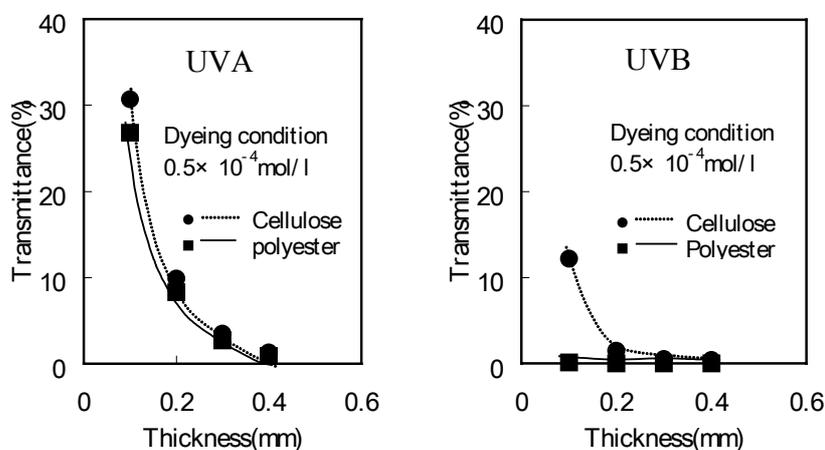
Figure 2. Relation between a thickness and transmission of dyed film.

The transmittance of film decreases with the increasing of the piled-up number of sheets, namely higher thickness of dyed film. The transmittance decreases rapidly upper the thickness of 0.2 mm. Generally, the threshold value of effective UV-blocking property would be bellow 10% in the UVT-transmittance. Table 2 shows the relations of the piled-up sheets and transmittance and UPF of dyed films. UVT-transmittance on a sheet of film is not less than 10% even in case of high dyeing condition and deep shade colored.

The deep shade films such as Direct Red 23(6) and Disperse Red 1(4) could not have the effective UV-blocking property with only one sheet. It is deduced that increasing the thickness of dyed film in order to get effective UV-blocking property is necessary.

Table 2. Relation of the piled-up sheets, the transmittance and UPF of film layer.

Samples	Number of sheets	Thickness of film layer(mm)	Transmittance(%)			A/N Standard		
			UVT	UVA	UVB	UPF	UPA	UPB
Direct Red23(4)(Deep shade)	**1**	0.02	**78.2**	**64.1**	**73.4**	**2**	**1**	**2**
Direct Red23(4)(Pale shade)	20	0.4	7.7	10.0	2.2	39	11	40
Direct Red23(5)(Medium shade)	15	0.3	6.4	8.9	1.5	54	14	56
Direct Red23(6)(Deep shade)	10	0.2	6.8	9.9	1.5	60	15	63
Disperse Red1(4)(Deep shade)	**1**	0.025	**56.0**	**38.8**	**5.4**	**10**	**2**	**10**
Disperse Red1(1)(Pale shade)	12	0.3	5.9	8.7	0.0	78	8	86
Disperse Red1(3)(Midium shade)	8	0.2	2.9	4.2	0.0	104	18	111
Disperse Red1(4)(Deep shade)	8	0.2	1.2	1.8	0.0	630	42	782

4. CONCLUSION

1) The UV-rays blocking property of non-dyed polyester film is excellent at UV-region, especially at UVB-region.
2) The polyester film is improved the UV-rays blocking property at UVA region by dyeing.
3) The cellulose film is improved the UV-rays blocking property highly at both UVA and UVB regions.
4) As the increase of the piled-up sheets of the films, UPF of the dyed film would be increase higher than the increase of UV-blocking efficiency.

ACKNOWLEDGMENTS

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Target-position dependence of the effect of the proportional concentration errors for dyeing polyacrylic with basic dyes

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ABSTRACT

In this research the effect of the proportional dye concentration errors has been examined with numerical experiments using optical data of basic dyes applied on polyacrylic. A larger set of target colours regularly spaced throughout the colour space has been chosen. For each target colour all available recipes have been treated and their sensitivities to proportional concentration errors have been predicted. It was found that, on average, the most sensitive to strength errors are the recipes for neutral and less saturated targets of about medium to low lightness. Fortunately, among different recipes for any such particular target also some recipes with very low sensitivity to strength errors can be found. The least sensitive to strength errors are the recipes for the target colours at the "lighter" part of the gamut border.

1. INTRODUCTION

Following Alman (1986) and Oulton and Chen (1995) in researches of Sluban et al. (2003a, 2003b) some measures for sensitivity of the recipe colour to strength errors were studied and experimentally checked on various different recipes for the neutral grey target colour with lightness $L^*=50$. The aim of this paper is to reveal a possible dependence of the predicted recipe colour sensitivity to strength errors upon the position of the target colour.

2. NUMERICAL EXPERIMENTS

The optical data of 8 basic dyes (2 yellows, 2 reds, 1 brown-red, 2 blues and 1 black) applied to textile fabric made of PAN polyacrylic fibres was used for match prediction. The producer assures the strength of all batches of any particular basic dye to be within $\pm 5\%$ of the average. Consequently, standard strength error of each particular dye was assessed to $5\%/3 \approx 1.7\%$. In each three-dye recipe (c_1, c_2, c_3) considered, the perturbations $\Delta c_1, \Delta c_2, \Delta c_3$ of initial dye concentrations c_1, c_2, c_3 corresponding to a 1.7% strength error were determined: $\Delta c_1 = 0.017\, c_1$, $\Delta c_2 = 0.017\, c_2$, $\Delta c_3 = 0.017\, c_3$. In order to simulate the combined effect of strength errors of individual dyes in the amount of one standard deviation the dye concentrations c_1, c_2, c_3 in the initial recipe were simultaneously changed according to the perturbation pattern of Oulton and Chen (1995). The pattern consists of 27 different combinations of small perturbations Δc_i, $i=1,2,3$. The resulted 27 colour changes and the corresponding CMC(2:1) colour differences ΔE_k, $k = 1,2,\ldots,27$; were predicted. The root mean square colour difference:

$$\sigma = \sqrt{\frac{1}{26}\sum_{k=1}^{27}\Delta E_k^2} \qquad (1)$$

is a measure of the *sensitivity of the recipe to the standard strength error*. It will be used to mutually compare the sensitivities of various recipes.

Additionally, for each recipe also a measure for its *sensitivity to random (weighing) error* was calculated. Standard random dye concentration error (fixed and independent for all concentrations, all dyes, and all targets) was assessed to be about $\Delta c_{\text{fix}} = 0.0003\%$. Then a measure for the sensitivity to random error was defined similarly to (1), as the root mean square colour difference:

$$\widetilde{s} \;=\; \sqrt{\frac{1}{26}\sum_{k=1}^{27}\Delta \widetilde{E}_k^2} \qquad\qquad (2)$$

The number $\widetilde{s}$ is the standard deviation of colour positions resulted from the perturbation pattern for individual dye concentrations in a recipe, but this time for all the recipes (and for all targets) all the concentration changes are equal to: $\Delta c_1 = \Delta c_2 = \Delta c_3 = \Delta c_{\text{fix}} = 0.0003\%$.

The target colours were chosen from 4 different L^*C^*-planes with hues 45, 126, 234, and 324, respectively. Targets have been spaced regularly by 10 units in L^* and C^* values. For each target colour and for all possible three-dye recipes for that particular target the sensitivities σ and $\widetilde{s}$ (to strength and random error, respectively) and the numbers $\Delta E_{\max} = max\{\Delta E_k ; 1 \le k \le 27\}$ and $\Delta \widetilde{E}_{\max} = max\{\Delta \widetilde{E}_k ; 1 \le k \le 27\}$ were calculated.

3. RESULTS

The pairs consisting of the predicted recipe sensitivity σ to standard 1.7% strength errors (1) and the recipe sensitivity $\widetilde{s}$ to fixed 0.0003% standard weighing error (2) for the recipes (containing the same combination of a yellow, a red and a blue dye) for targets from the red-violet L^*C^*-plane of hue $h = 324^o$ are presented in Table 1. For the same recipes and targets the corresponding pairs of maximum $\Delta E_{\max} = max\{\Delta E_k ; 1 \le k \le 27\}$ of colour differences ΔE_k appearing in (1) and the maximum $\Delta \widetilde{E}_{\max} = max\{\Delta \widetilde{E}_k ; 1 \le k \le 27\}$ of colour differences $\Delta \widetilde{E}_k$ appearing in (2) are presented in Table 2.

In Table 1 a kind of regularity can be seen for sensitivity to 1.7% proportional errors (numbers σ, in bold). When the target colour is moved down along grey axis to darker greys the sensitivity σ of recipes increases from its minimal value 0.26 to reach its maximal value 0.57 at lightness 40 and then a moderate decrease of the sensitivity σ occurs. The situation is similar along each line of constant chroma C^* (and hue $h=324$), only the magnitudes of the sensitivity σ are smaller. If (at the constant lightness L^* and hue $h=324$) the target colour is moved radially away from the grey axis to saturated colours the sensitivity σ of recipes decreases from its maximum at the grey axis (or nearby) and reaches its minimal value at the border of the gamut. The target-position-dependence of sensitivities to random weighing errors (the quantity $\widetilde{s}$) is essentially different. Sensitivity $\widetilde{s}$ is the biggest for the recipes for the lightest neutral target, where it is also essentially bigger than sensitivity σ. When the target is moved to darker and/or saturated colours the sensitivity $\widetilde{s}$ rapidly decreases to very small values that are practically negligible in comparison with the sensitivities σ. In Table 2, as expected, the same kind of target-position-dependence can be seen as in Table 1. The only difference is that in Table 2 each particular value $\Delta E_{\max}$ (in bold) or $\Delta \widetilde{E}_{\max}$ is in most cases 40-60% bigger than the equally-positioned value σ or $\widetilde{s}$ in Table 1. The same kind of target-position-dependence of sensitivities of recipes to strength and random concentration error was observed also for recipes for targets in other L^*C^*-planes considered (hues 45, 126 and 234).

Table 1. The pairs consisting of the sensitivity σ to standard 1.7% strength errors (1) and the recipe sensitivity $\tilde{s}$ to fixed 0.0003% standard weighing error of the recipes (containing the same combination of a yellow, a red and a blue dye) for each of the red-violet targets indicated in L*C*-plan of hue h=324.

Targets: h = 324	$C^*=0$	$C^*=10$	$C^*=20$	$C^*=30$
$L^*=80$	**0.26** ——— σ 0.85 ——— $\tilde{s}$			
$L^*=70$	**0.44** 0.47	**0.27** 0.29		
$L^*=60$	**0.54** 0.25	**0.34** 0.16	**0.23** 0.13	
$L^*=50$	**0.56** 0.13	**0.38** 0.09	**0.26** 0.07	**0.20** 0.07
$L^*=40$	**0.57** 0.07	**0.39** 0.05	**0.27** 0.04	**0.21** 0.04
$L^*=30$	**0.44** 0.04	**0.37** 0.02		

Table 2. The pairs consisting of the maximal predicted colour differences ΔE_{max} and $\Delta \tilde{E}_{max}$ of recipes (containing the same combination of a yellow, a red and a blue colorant) for each of the red-violet targets indicated in L*C*-plane of h=324.

Targets: h = 324	$C^*=0$	$C^*=10$	$C^*=20$	$C^*=30$
$L^*=80$	**0.39** ——— ΔE_{max} 1.30 ——— $\Delta \tilde{E}_{max}$			
$L^*=70$	**0.66** 0.72	**0.41** 0.43		
$L^*=60$	**0.82** 0.38	**0.52** 0.24	**0.37** 0.19	
$L^*=50$	**0.84** 0.19	**0.58** 0.13	**0.41** 0.11	**0.32** 0.11
$L^*=40$	**0.85** 0.10	**0.59** 0.07	**0.42** 0.06	**0.33** 0.06
$L^*=30$	**0.64** 0.06	**0.57** 0.02		

The observed target-position-dependence of the sensitivities of recipes to proportional and random concentration errors is not the feature of only the single three-dye combination considered in Tables 1 and 2, it is also valid generally, as it will be seen next.

In Table 3 for the same indicated targets from the red-violet L^*C^*-plane of hue $h = 324$ we present the triplets consisting of: above – the sensitivity σ of the most sensitive recipe, bold in the middle – the average of predicted sensitivities σ of all recipes matching that target, and bellow – the sensitivity σ of the least sensitive recipe. In Table 4 for the same targets from the L^*C^*-plane of hue $h = 324$ we present the triplets consisting of: above, the biggest $\Delta E_{max} = max\{\Delta E_k; 1 \le k \le 27\}$ across all recipes, bold in the middle, the average of predicted ΔE_{max}'s of all recipes matching that target, and bellow, the smallest ΔE_{max} across all recipes.

From Tables 3 and 4 it can be seen that, on average, the less sensitive to strength errors (and thus producing a smaller corresponding $\Delta E_{max} = max\{\Delta E_k; 1 \le k \le 27\}$) are the recipes for targets on the lighter part of the gamut border. The most sensitive to strength errors are, on average, the recipes for neutral and less saturated target colours of (approximately) medium lightness. It is useful to note that for a particular target, except for very saturated ones, recipes with essentially different sensitivities to strength errors can be found.

CONCLUSIONS

Numerical experiments show that in dyeing polyacrylic with basic dyes, generally, the impact of strength errors on recipe colour is the smallest for recipes for the target colours at the "lighter" part of the gamut border. On average, the most sensitive to strength errors are the recipes for neutral and less saturated targets of about medium to low lightness. Fortunately,

among different recipes for any particular target in most cases also some recipes with very low sensitivity to strength errors can be found. Further, the sensitivity of the recipes to strength errors has essentially different target-positions dependence than the sensitivity of the recipes to random concentration errors, which is the biggest for recipes for the lightest neutral and less saturated colours and almost negligible for dark-shade recipes.

Table 3. The triplets consisting of the maximal (above), average (bold in the middle), and minimal (beneath) predicted recipe sensitivity σ (to standard 1.7% strength errors) of all recipes matching the red-violet targets indicated in the L*C*-plane of hue h=324.

$L^*=80$	0.26			… max.
	0.19			… aver.
	0.09			… min.
$L^*=70$	0.44	0.27	0.18	
	0.29	**0.21**	**0.18**	
	0.10	0.15	0.16	
$L^*=60$	0.54	0.34	0.23	
	0.34	**0.26**	**0.20**	
	0.11	0.16	0.17	
$L^*=50$	0.56	0.38	0.26	0.20
	0.35	**0.29**	**0.22**	**0.18**
	0.11	0.16	0.17	0.17
$L^*=40$	0.57	0.39	0.27	0.21
	0.41	**0.30**	**0.22**	**0.19**
	0.12	0.16	0.16	0.17
$L^*=30$	0.53	0.37		
	0.38	**0.28**		
	0.12	0.16		
Targets: h = 324	$C^*=0$	$C^*=10$	$C^*=20$	$C^*=30$

Table 4. The triplets consisting of the maximal (above), average (bold in the middle), and minimal (beneath) predicted colour differences ΔE_{max} (for combined 1.7% strength error) of all recipes matching the red-violet target indicated in the L*C*-plane of hue h=324.

$L^*=80$	0.39			… max.
	0.29			… aver.
	0.15			… min.
$L^*=70$	0.66	0.41	0.29	
	0.45	**0.34**	**0.28**	
	0.17	0.26	0.27	
$L^*=60$	0.82	0.52	0.37	
	0.53	**0.42**	**0.32**	
	0.16	0.28	0.28	
$L^*=50$	0.84	0.58	0.41	0.32
	0.54	**0.46**	**0.35**	**0.29**
	0.15	0.29	0.29	0.28
$L^*=40$	0.86	0.59	0.42	0.33
	0.63	**0.47**	**0.36**	**0.30**
	0.16	0.28	0.29	0.27
$L^*=30$	0.81	0.57		
	0.58	**0.44**		
	0.15	0.26		
Targets: h = 324	$C^*=0$	$C^*=10$	$C^*=20$	$C^*=30$

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Influence of chemical structure of dyes on decolouration effects

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ABSTRACT

From the ecological and physiological point of view the effluents from textile industries are the most expressive polluted. For achieving the water of high quality for recycling use the most important thing in decolouration of effluent is removal of dyes and others compounds. On the base of the fact that decolouration of textile dye effluent with azo dyes gives the best results the most methods are based on the removal of these dyes.

The aim of this paper is achieving the complete decolouration of wastewater with different chromogen dye systems. For such purpose the effluent with next two reactive and two acid dyes are chosen: C.I. Acid Blue 158 (azo), C.I.Reactive Blue 19 (anthraquinon), C.I. Acid Red 52 (xanthen) and C.I. Reactive Blue116 (phtalocyanin).

The decolouration of dyed water was carried out by the next methods: using Fentons reagent (with and without ultrasound) and coagulation/flocculation method. The degree of decolouration was determined spectrophotometrically. Additionally it was determined the biodegradable of dye as BOD_5/COD value. It was concluded that total water decolouration is achieved only in the case of water coloured with azo dye.

1. INTRODUCTION

Textile industries consume the large volumes of water and chemicals for wet processing of textiles. The chemical reagents used are very diverse in chemical composition, ranging from inorganic compounds to polymers and organic products (Mishra and Tripathy 1993). The presence of very low concentrations of dyes in effluent is highly visible and undesirable (Nigam et al. 2000). Many dyes are difficult to decolourise due to their complex structure and synthetic origin. There are many structural varieties of dyes that fall into either the cationic, nonionic or anionic type. The effluents thus generated contain a wide range of contaminants, such as salts, dyes, enzymes, surfactans, scouring agents, oil, oxidizing and reducing agents.

Different methods are used for the purification and decolouration of textile coloured wastewater: mechanical, chemical, physical-chemical and biological or their combination (Schulze-Rettmer 1998, Ferrero 2000, Parac-Osterman et al. 2002).

2. MATERIAL AND METHODS

2.1 Dyestuff

Investigations were performed on coloured wastewater containing 1 g/l dyestuff of different chemical constitution:
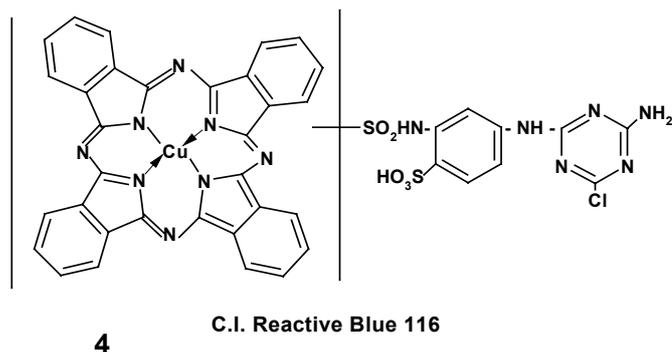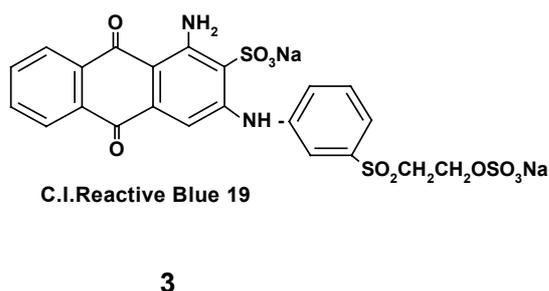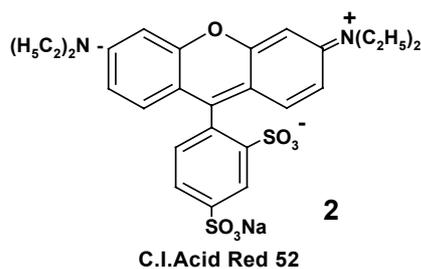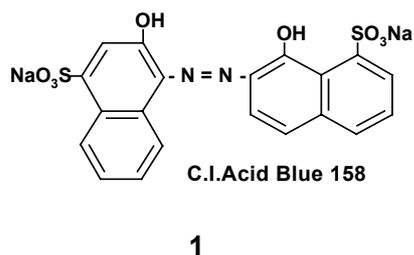
2.1 Methods

The decolouration of dyed water was carried out by the next methods: using Fenton's reagent (with and without ultrasound) and coagulation/flocculation method.

Fenton treatment ($H_2O_2 – FeSO_4$)
Process was carried out with and without ultrasound at 25 ^{0}C and 60 ^{0}C: In 1 g/l dye solution were added: 0.5 ml/l H_2SO_4 p.a.(pH3), 50 ml/l H_2O_2 36% and 5 g/l $FeSO_4$. Coloured wastewater was mixed 15 minutes with magnetic mixer (700 rpm). pH 8 was set with NaOH 32%.
   Changing of concentration of dyes in wastewater was measured spectrophotometricly on Carry 50. Degree of decolouration is shown on Figure 1.

Coagulation/flocculation method:
The wastewater was treated with the coagulant 0.1% Beifloc ACI (CHT) (modified polyacrylamide, anionactive,) and in jar testes were carried out at a particular coagulant dosage, pH 7, was mixed 30 minutes (100 rpm). After the addition of the coagulant was added 7.5 ml/l flocculant Beifloc CV (CHT) (condensation nitrogen compounds, cationactive) was mixed 10 minutes (50 rpm). After 24 h samples were filtered through cotton fabric. Concentration of dyes in effluent was measured spectrophotometricaly on Carry 50 (Varian). Degree of removed dyes is shown on Figure 2.

Wastewater biological control:
Before and after decolouration treatments the COD and BOD_5 were measured (according ISO 5000) and determined the biodegradability of dye as BOD_5/COD value (Figure 3.)

3. RESULTS

Figure 1 and 2 show the results of water decolouration after Fenton's and coagulation / flocculation treatment, respectively.
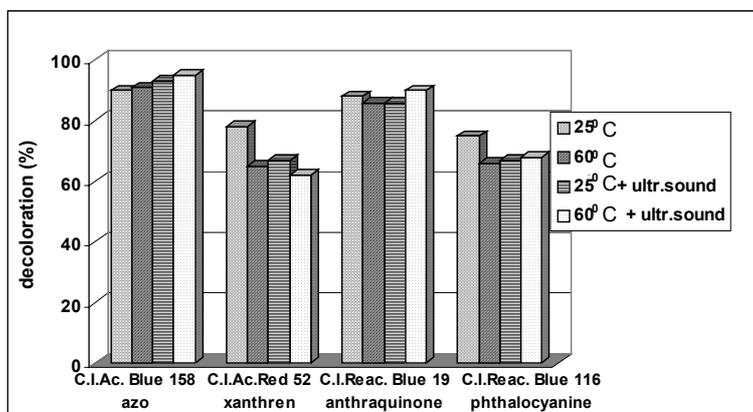
Figure 1. Degree of decolouration after Fenton treatment.
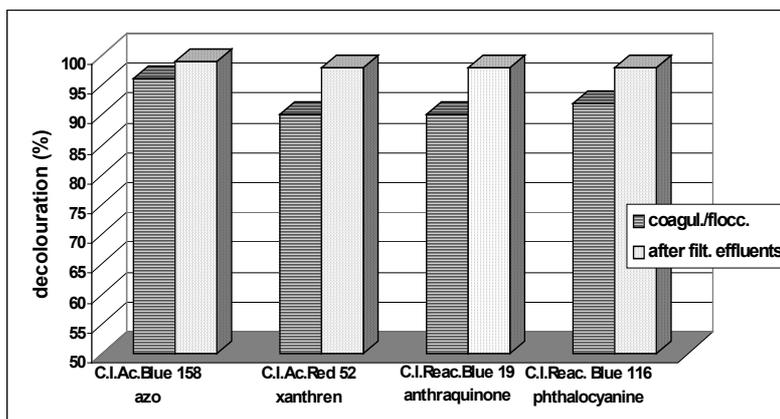
Figure 2. Degree of water decolouration after coagulation / flocculation treatment.

Biodegradability of dyed water before and after treatment can be seen on Figure 3.
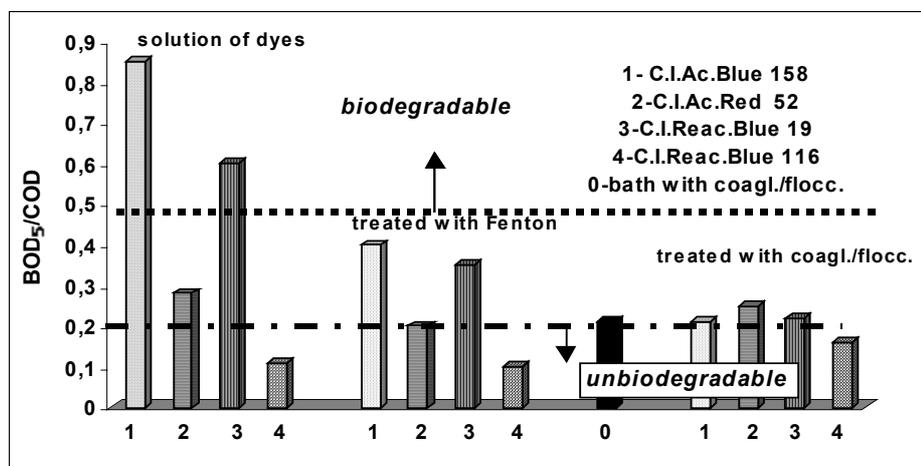
Figure 3. Biodegradability of dyes: BOD_5/COD values of water before and after the treatments.

4. CONCLUSION

The coloured wastewaters with four dyes with different chromogen system were decolourated with the next methods: chemical oxidative method using Fanton reagent and physico-chemical, coagulation/flocculation method.

Fanton reagent has multifunctional activity having the oxidative and flocculation action. The lack of this method is the low oxidative degradability of some dyes, as the consequences of molecule stability.

The lowest decolouration degree are shown in the case of acid dye C.I. Acid Red 52 with xanthen chromophore (80%) and for C. I. Reactive Blue 116 with phtalocyanine copper complexon.

It is expected, as in the literature accepted, the highest decolouration degree given for azo - dye, C.I. Acid Blue 158.

The dyeing temperature above 25°C decreases the activity of Fanton's reagent because the catalytic degradation of H_2O_2 is happened.

With exception of azo dyes, by using the combination of Fanton's reagent/ultrasound, there is no considerable decolouration effect of other dyes.

It is confirmed, that chemical effect of water decolouration depends on molecular stability and for such reason the priority is given to physico-chemical methods. Applied coagulation/flocculation methods are shown very high decolouration degree of more than 95%.

After the decolouration of effluents, according ISO standard, the water has to be biologically controlled. It is very often given by BOD_5/COD values. Coloured waters, with exception of phtalocyanine dye, treated with Fanton's reagent are more biologically accepted, having the BOD_5/COD values less than 0.2.

Coloured water treated by coagulation/flocculation method, without any father filtering procedure, biologically loads the water. It is confirmed by given very low degradability biological values that is lower than 0.2.

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ARCHITECTURE, DESIGN,
ARTS, AESTHETICS

The colour-system of architectural structuralism:
The office complex Garnisonen, Stockholm, Sweden

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ABSTRACT

The Swedish architectural structuralism is closely connected to the golden years of Swedish economy when standardisation and rational prefabrication were prerequisite. The foundations were Anglo-Saxon post-war architectural theory as well as English and Dutch practice. The giant office complex Garnisonen on Karlavägen in Stockholm (1969-1972, Tage Herzell, A4 / ELLT architects) has a uniform facade covered in plates of dark aluminium that stretches 347 meters. The pedestrian arcade opens up to inner courtyards of a more intimate character. The interior, as well as windows and doors, were given manifest strong colours according to an organised system. Which motives and influences can be found in the choices of colour-zones in pure blue, red, yellow and green, combined with unpainted concrete? The investigation shows that colours are used as a sublimation of technology in the super-rational system of modular building, as an element of rebellion associated with play (a kind of lego or meccano) as well as an agent in the contemporary strife for an informal, relaxed and more democratic working life. The colour-system resembles a drawing (*a picture*) of a technical flow-chart —a frozen three-dimensional flow of energy, water and air. The paper is also attempting to discuss the modernistic roots of architectural structuralism through the concept of *addition*.

1. INTRODUCTION

> *"A complicated three-dimensional system of communication*
> *runs through the building like water flowing in a tree."*
> The artist Gösta Wallmark (2003) commenting the colour-system in Garnisonen

The architecture of the 1960's and 1970's is fascinating. The attitude towards planning and building was so different compared to the traditional approach to the city. Modernism was about to peak and the scale and the speed in building were reaching new fantastic goals. In just a few years it all turned over because of the oil-crisis, the awakened understanding of environmental problems and the questioning of the repetitive architectural forms. The times have changed but the buildings are still there, sometimes told off and criticized, but some of them exceptionally charged with expression.

The critique of the architecture of the 60's and 70's often contains clichés underestimating the colouring. My question is: Which influences and motives can be found behind the choices of strong and pure colours in relation to unpainted concrete? As a case I have chosen the giant office-block Garnisonen (1969-1972), situated on Karlavägen in Stockholm. The choice is based on the fact that the building manifests itself with colours —it is identified as the building with "the typical colours of the 70's".

The project was lead by the architect Tage Herzell at A4 architects. He gave Garnisonen a uniform facade stretching one entire block in length (347 m), covered with an even and dark,

anodised aluminium. Above a pedestrian arcade and a storey with large glass-facings were placed another five storeys containing small office-rooms. The long, thin and tall structure facing the street was placed on pillars allowing views further into the inner courtyards. The tall street-slab is gradually succeeded by lower volumes, creating a more intimate scale in the centre of the block. Elevator towers in unpainted concrete mark in every 50 meters a recurrent rhythm. The interior, but also in window- and door-sections, strong colours prevailed according to a set system. The building was divided into colour-zones of blue, yellow, green and red combined with unpainted concrete. In each zone, with exceptions, technical installations were given specific colours signalling their use —for example blue for air, red for electricity and yellow for electric fittings.

One important source in my study has been the interviews with the person responsible for the original colouring and art-program of the building: the artist Gösta Wallmark. I have chosen the concept *colour-system* as a way to connect the colouring to this specific period in time.[1] The architectural structuralism in Sweden, with its meticulous public engagement in the development of a rationalized and standardized building process, was given a specific name: the system-architecture. *Colour-system* is in this context indicating a close relationship and is also giving associations to technical installations —a fruitful joint in the analysis.

In order to paint a modernistic background to the architectural structuralism and the system-architecture I have used the concept *addition*, to add piece by piece. The concept is present in the early modernism (19th century, France) and returns in 20th century architectural theory, in the description of architectural structuralism as well as in the organisation of the practical work in creating Garnisonen, which consists of standardised and modularised "building-boxes" added piece by piece.

2. THEORY OF ARCHITECTURAL STRUCTURALISM

Structuralistic thinking has one of its roots in linguistics and a model for building language developed in the beginning of the 20th century: *langue et parole* by Ferdinand de Saussure (Lüchinger 1981: 15). Structure as a concept was also to be used within the fields of biology and sociology but was most common within architecture (Forty 2000: 281ff). How *addition*, a central concept within the architectural structuralism, was used among architects can be illustrated with the following words by the Danish architect Jörn Utzon: "A building-project is like an organic world, an organism where cell is added to cell".[2]

Addition (to add part by part) as a working-method in the creation of architecture was not a new idea introduced by the structuralists but was consciously present already in the 19th century neo-classicism. It was made manifest through the wide-known achievements of the architect Jean-Nicolas-Louis Durand with his work *Précis* (1819). Durand was the pupil of Boullée and taught architecture to students in engineering at the École Polytechnique in Paris in the beginning of the 19th century (Mårtelius 1988: 30).[3] He had made the observation that the engineers more frequently were given the responsibility to create buildings (Durand 1819:

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[1] The concept colour-system is normally referring to, for example, NCS or Munsell (Fridell Anter 2000).

[2] Utzon again: "A consistent use of industrially produced building components are achieved only when parts are possible to add one to another into buildings without any change or reduction. Such a pure principal of addition will give a new form of architecture, a new architectural expression with the same character and the same effect as the addition of trees in the wood, groups of animals." (Ekholm et al. 1980: 17ff).

[3] École Polytecnique was so integrated with École des Beaux-Arts that they can be understood as educations under one and the same flag.

vol. 2, sect. A). The method in *Précis* was based on the logics of the language; vertical enclosures, roofs, foundations, floors, terraces, arches, vaults and different openings were just like words in a language (Forty 2000: 79f). In a step by step adding of a larger amount of given parts it would, according to Durand, be possible also for engineers to create great architecture in no time.

The principle of addition in architecture echoes in the writings of the architectural historian, theorist and cultural critic Peter Reyner Banham, an Englishman acting in England after the Second World War. The publication in 1960 of his dissertation *Theory and design in the first machine age* initiated a critical analysis of architectural modernism and its roots (Mattsson 2003: 30). The book, at the same time as being a source for historical studies, presented a strong will in the direction of contemporary architecture. His opinions in this sense were to exercise great influence on the new brutalism, a movement where the architects Alison and Peter Smithson were the prominent figures.[4] The new brutalists wanted an architecture that could meet the challenge of expandability and change in a new society of consumption. Architecture should be added together piece by piece and be possible to change according to new needs. Banham's identification of this development in architecture makes, as he puts it, "Durand's ideas one of the neo-classical foundations on which modern architectural theory rests".[5]

Addition, an important variable in 19th century neo-classicism, was hence reconsidered through Banham and reused in a new modernistic situation. And the new brutalism became the foundation of architectural structuralism.

3. THE SYSTEM-ARCHITECTURE IN SWEDEN

A good basis for the development of architectural structuralism in Sweden was the growing need for buildings (Svedberg 1988: 163, *Arkitektur* 1972). The expansion of the public sector, and the demand for more and better housing led to an increase in building-activities. Distinct Swedish examples are the Huddinge hospital (first stage 1967-1972) and the Arrhenius laboratory at the University of Stockholm (1971-1973). The great mass-production of housing (1965-1975) is another important result of the structure philosophy.

One of the most significant examples of the Swedish structuralism, the huge office-complex Garnisonen, was commissioned by the state. Through this building, placed in the centre of the capital, different public departments could be placed under the same roof and important large-scale economical advantages could be earned.

The board for stately run building-activities initiated the Garnisonen-project in 1964 and the commission was given to A4 architects under the supervision of architect Tage Hertzell the following year (*Arkitektur* 1972). A4 was working together with the architect-office ELLT in the development and implementation of the "building-box", a standardisation that would be set and used for many office-buildings.

The central keywords were to be generality and variability in relation to different activities and tenants. The parts of the building that could be reused when activities changed should be of a universal character. The parts of the building that would have to be adjustable should be easy to remove and exchange.

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[4] Important works are the school in Hunstanton in Norfolk (1945-1951) and their contribution at the conference in Otterloo 1959. Another influencial architect in the development of the architectural structuralism was the Dutch architect Aldo van Eyck (Nygaard 1995: 57).
[5] Banham (1960: 15-16, footnote) is here referring to the lesson on page 6 in *Partie graphique* (1821), the supplement to *Précis*.

4. ANALYSIS OF THE COLOUR-SYSTEM

The office-building Garnisonen cannot be characterised as a simple addition of parts. Instead the building appears, one could say, as time-less; its architecture has "classical" features such as well-balanced spatial proportions, legibility and other qualities. The colour-system is an inseparable part of the architectural expression and plays an important role merging the work into a totality.

The exterior of Garnisonen facing Karlavägen is an introvert plane surface, "infinite", without any variations, making the eye loose its ability to measure length and size. The choice of a dark colour in aluminium is a striving to adjust this giant structure to the 19th century street scene.[6] The whole block is also part of a border where the older 19th century grid of Stockholm ends and a more openly built environment takes over. While this exterior could be seen as strictly *serious* the inner courtyards, and above all, the interior expresses something else.

When Le Corbusier was passing in an aeroplane over North Africa in 1935 he, in the perspective from above, got a vision of structural and general forms (Lüchinger 1981: 68). The villages gave an irregular but still uniform impression. He published his observations in the book *Aircraft* with the intention to effect city planning (Le Corbusier 1935). He also used them in his own planning, in for example "La Ville Radieuse". Structuralists were attracted by the idea and they used the "perspective from above" as a canon for how architecture and city planning should be presented and discussed (Lüchinger 1981: 68). The scale could be enormous as in the so-called "mega-structures", where the perspective was set from space. But the structuralists also used the "perspective from above" on a smaller scale. With a look at Garnisonen, and how the colour-system of the building is presented, in the 1970's as well as in later publications, we see a two-dimensional picture "from above". The colour-system is presented with drawings looking just like an engineers' plan for installations or maybe like a flowchart for the electrician. The source of the colouring is without doubt the technical colour-codes used by engineers. The technical installations in the building are blue for ventilation, red for electricity and yellow for the electric fittings. Except where the artist made exceptions. The exceptions could be dimensions of the pipes or the choice of colour not following the technical use (as for example the yellow ventilation-pipes above his own art-work *Yellow wall* on the entrance floor). The strong and pure colours are inspired by pop-art, the clothes of the 60's (Mah-Jong) or maybe the film *Yellow submarine* (1968) with the Beatles. The whole building is put together like a large meccano for children, with the colours of lego. The colouring of the corridors was inspired by the warm after-noon light on Roman facades. The effect, according to the artist, was meant to resemble "walking in coloured light" —a description with psychedelic value.[7]

The serious references to rational Swedish structuralism and the playful exceptions are the key to understanding the double-nature of the colour-system in Garnisonen. A comparison with the colouring of two other important works in the structuralist tradition can make the perspective more clear: the colours used in the earlier mentioned Huddinge hospital and the colours of the Cultural Centre George Pompidou in Paris (1972-1977). In Huddinge hospital the colours only have one single and serious role: to guide.[8] Each storey in this enormous complex has a specific colour (brown, green, yellow, red and blue) used in the flooring and the furniture. In the Centre George Pompidou seriousness is completely absent and the playful

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[6] At the time the originally vividly and lightly coloured 19th century building were not renovated, hence brown and some of them almost black.

[7] This effect and colouring was not preserved in the recent refurbishment.

[8] There are however an exception in one auditorium (the Birka hall).

references and the game of technology has taken over. Colour and technical installations are used in a fantastic, mannerist and respect-less way as a bridge to art.[9] The use of colours in Garnisonen can be found in between these examples.

In the introduction-quote Gösta Wallmark describes the colour-system through a biological metaphor, which works perfectly in a structuralist context: "A complicated three-dimensional system of communication runs through the building like water flowing in a tree". This reconnects to the new brutalists and futurists ideas about "flow as a frozen and abstract thing in itself".[10]

Alison and Peter Smithson considered the infrastructure of a city as a *picture*, a linking symbol in townscapes. The highways were the structural blood-flow, giving oxygen (sic) to a new urban reality. The picture should work symbolically on different levels and different scales. In this way the picture of the infrastructure could easily be linked to the picture of the inner networks of the buildings.

The colour-system of Garnisonen is clearly the *picture* of a frozen flow. It is a metaphor of movement and constant growth that links the office-boxes into an architectural whole. At the same time colour is used as a contrast to the super-rational modular building, a rebellion associated with play (a lego or meccano) and contemporary striving for a more relaxed and democratic working-life. The colours are organized in a system, resembling a drawing (*a picture*) of a technical flow-chart —representing a technological enthusiasm in sublime interpretation: A frozen three-dimensional flow of energy, water and air.

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[9] Richard Rogers was inspired by the Garnisonen-project on the spot in Sweden (Castenfors 2002: 12).
[10] Charles Jencks, quoted in Mattsson (2003: 76). Jencks is with these words connecting Smithsons via Louis Kahn back to the futurists.

Colour and light in architecture

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ABSTRACT

Physically speaking colour and light belong to a single radiant spectrum so, without light colour cannot exist. However, many investigations fail to take this basic fact into account. This is so even in the field of architecture, which prefers to deal with both aspects separately, thus restricting the scope of future research and producing a discourse which has become both partial and repetitive. The objective of this paper is to attempt to suggest new avenues for research in simply studying both aspects in conjunction.

1. INTRODUCTION

By failing to recognize that light and colour in architecture are two different aspects of the same problem, and therefore indivisible, research into the two areas has generally followed different paths. In the field of lighting research it has mostly aimed to solve aspects of visibility and comfort, while in the field of colour attempts have been made to solve the needs of design, style and fashion, but have not always been based on verifiable data and/or criteria. This has led some to believe that "everything is possible", while others take the view that it is a "topic for specialists". However, both views are misguided. Thanks to the labour of qualified architects and designers, and with the evidence of their work all around us, no doubt remains today as to the importance of their research.

In particular, psychophysical methodology applied to the analysis of individual or multiple variables, has allowed certain criteria to be established and basic aspects to be resolved both in the field of colour and in lighting, and although few persons are interested in colour and light *per se*, the importance of these investigations in solving basic aspects which contribute to human comfort is today widely recognized. Therefore, it appears that these investigations have a prosperous future ahead of them in helping us to understand and improve fundamental aspects of life such as health, the economy, security and even emotion and feeling.

Where does research stand today? How do light and colour behave in each one of us? There appear to be three paths: the visual system, the perceptive system as made possible by the cognitive system, and the circadian system. To date we have sufficient knowledge on the visual and cognitive system on which to base valid research in the area. However, until the present day, research in lighting has only been carried out in connection with problems of visual comfort or discomfort, and in the field of colour in aspects which have to do with reproduction, constancy, memory, ranges or simply the study of its variables. In both cases, it is still necessary to investigate the general state of the observers in specific situations which may influence good daily performance. For this reason we believe that a holistic vision of the way in which colour and light are applied in design is still some way off.

Finally, the circadian system is still the subject of study, despite the fact that it is our body clock. Recent research has shown that in addition to the system of cones and rods there is another photoreceptor system which regulates the circadian system and physiology. Disruption of both systems, which can result from seasonal, daily and acute changes in

habitual exposure to light, may contribute to a variety of clinical and non/clinical disorders. The responses of this novel pathway include circadian phase/shifting and melatonin suppression (Figure 1), as shown in data from the recently published action spectrum for melatonin in humans (Brainard, Kavet and Khifets 2001, Thapan, Arendt and Skene 2001). A better understanding of melatonin may afford a deeper insight into many of man's biological responses to colour and light, and help in the treatment of disabilities like jet lag and SAD.

From the above it should be apparent that lighting and colour research in architecture has certainly not reached the end of the road, but rather it is at a crossroads: one way indicates "more of the same", while the other, labelled "new directions", leads to a new field where the impacts of colour and lighting through the perceptual and circadian system are examined. Figure 2. There can be no guarantee that taking this road will lead to more fruitful research, but constant repetition of what is already well known is also a pointless exercise. It is often claimed that research is undertaken as if it were a "fishing expedition" in which the different variables have been tested to see the possible effects. Nothing is usually found.

At this state of affairs, this paper seeks to propose certain new avenues of investigation.
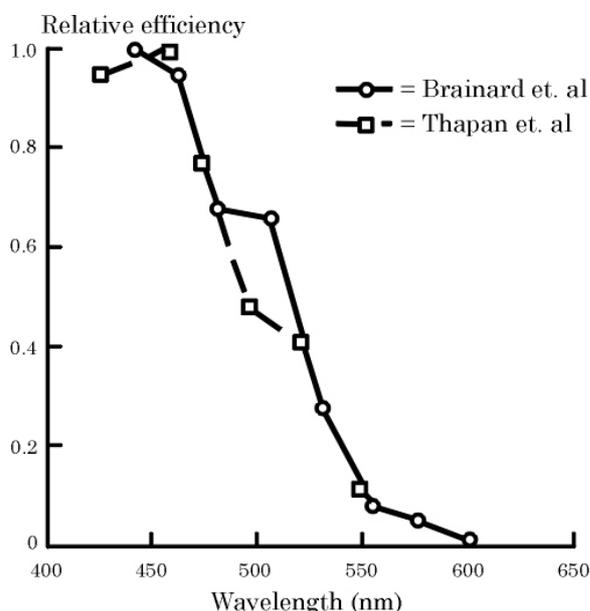
Figure 1. Measured relative efficiency of electromagnetic radiation at different wavelengths in stimulating human circadian system, using melatonin suppression as a marker (from Brainard, Kavet and Khifets 2001, Thapan, Arendt and Skene 2001).

2. PROPOSALS

The use of colour to improve and organize underprivileged areas, as a means of stimulating the inhabitants to take better care of them and to protect them, is a good starting point. As a result of its use, we have been able to witness a reduction in the crime rate, since the space in question was no longer totally anonymous, and this led to an increase in solidarity amongst its inhabitants. Needless to say, it is accompanied by adequate illumination, the area recovers its identity, colour becomes more effective and in turn security increases.

Another aspect to be studied in greater depth is the effect that colour and light have on the visual, perceptive and circadian systems, as shown in Figure 2. The first and the last ones are known to be sensitive to different zones of the chromatic spectrum, as shown in Figure 1, but what are the implications of these differences? Although it is not at all certain, these differences would appear to stimulate the argument on how light and colour affect the mood and behaviour of people from a holistic viewpoint. We should not forget that the field of environmental psychology is inherent to architecture, a discipline which is viewed subjectively by users and not only from technical and economic parameters.
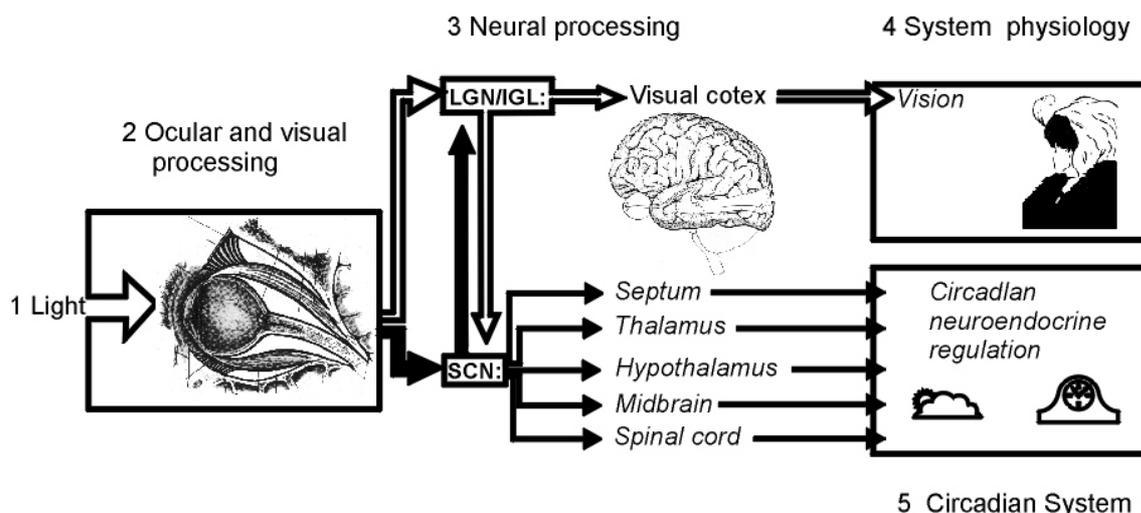
Figure 2. The diagram above provides a simplified explanation of the neuroanatomy that is responsible for mediating both the sensory capacity of the visual system and the non-visual regulation of circadian and neuroendocrine functions. LGN: lateral geniculate nucleus of the thalamus; IGL: intergeniculate leaflet of the thalamus; SNC: suprachiasmatic nucleus of the hypothalamus.

These studies appear to assess not only visual or bodily discomfort but also psychological and attention discomfort.

Another issue that deserves greater attention is the concepts on which colour research is based. Prior reading and a thorough analysis of the subject to be studied are vital; in other words, the widest possible knowledge of already existing studies. Although this background knowledge can only be obtained over time, it not only prevents the recycling of existing research but it also stops researchers pursuing fields of study which are alien to the aims of their research. This precaution is of paramount importance and if it is ignored, no progress in research can be made and its significance is lost. For example, the concept of comfort for many is simply the absence of discomfort, but this simplicity fails to adequately clarify the problem. Nor does it help to quantify it since comfort and discomfort do not belong to the same continuum, and therefore cannot be quantified with the same criteria (Helander and Zhang 1997). Both comfort and discomfort generally have to do with esthetical values and well being, even with sumptuosity and happiness. They change with culture, fashion and the interests and/or expectations of the user. So, how can these variables be measured? How can these very valid guiding principles become generalized, the aim of any investigation?

The example makes us aware of the need to establish new methods with which to measure *the message* or *messages* that a light and colour project seek to convey to the user. In cases such as these, questionnaires using some form of rating scale are generally applied. The difficulty resides in establishing the right questions, particularly unambiguous ones.

It is important to remember that different architectural contexts and users will assign different degrees of importance to the use of light and colour. For instance, the requirements of an office clearly differ from the needs of a meeting room although both are part of the same administrative nucleus. We could give several similar examples but in general research fails to consider the sensitive opinion of users. It should also be remembered that both light and colour are "builders" of space, apart from functioning as "guides" within it, aspects which call for further detailed exploration. It should be noted that most of these unresearched subjects have to do with the failure to treat colour and light jointly. Studies on the robustness of these effects of colour and lighting on behaviour are certain to introduce a new perspective.

Another issue to be decided is the level of precision and participation that each variable

requires in a particular investigation. For example, in another paper presented at this very meeting, we analysed the legibility of different alphabets and messages, assessing the contribution of colour and contrast. The data obtained confirms the importance of contrast over colour, be it chromatic or non-chromatic, for good legibility. Colour no doubt attracts a reader's attention, but if contrast is excluded or reduced, legibility also suffers. In each architectural space it is important to discuss the role of light and colour and how much can be lost if either of the two factors is neglected. According to the case, the answer to these questions may require high or medium precision; once again a loading bay cannot be treated as if it were a theatre. Common sense must prevail in any piece of research.

Another point to be contemplated is the search for the appropriate method according to the data one wishes to obtain. The time invested in preparing the experiment will be reflected in the quality of the results. For example, if the behaviour of users in a certain space is to be analysed, observation of the users will be the most effective method. However, laboratory studies will provide merely very general guidelines that are only necessary at the start of experimentation. The behaviour of users when faced with light and colour designs is generally seen through subjective variables that have no relation to physical stimuli, something that does not occur when colour and light are studied at a laboratory with psychophysical methods.

Another aspect which is considered very little in the field of colour, once again due to the fact that light is neglected, is what happens with form and space as the day proceeds and natural light becomes artificial. What is the influence of light and colour in changes in mood and productivity at different moments of the day?

A lot has been said about the effect of colour on people, and its healing effects. Let us remember that to begin with we spoke of the influence of light on the circadian system, which could be used to treat sleep disorders and to stabilize rest-activity cycles in people with Alzheimer's disease, and the depressive states which result from an inadequate absorption of melatonin. As shown in Figure 2, light in the circadian system covers a specific spectrum. But if we speak of "healing colours", can we say that this assertion is at all related to this system? Evidently, the effect of light on the visual and cognitive systems leads to perception, but no suggestion of a link with any kind of disorders has been made. Once again we are faced with questions that have no definitive answer.

We could suggest other possible lines of research but we believe that those we have mentioned are enough to show that the subject of colour is intimately related to lightning and even to the physiology and the emotion of man, and that these factors together cannot be ignored without falling into a sort of reductionism. There is room for priority, but forgetfulness or ignorance cannot be forgiven.

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Paul Scheerbart's utopia of coloured glass

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Points of departure for my presentation of Paul Scheerbart and his architecture of coloured glass are the concepts of *utopia* and *transparency*. In regard of the theme of the meeting, "Colour and Paints", one might reflect on whether transparency contains either colour or paint, or both of them.

The German poet Paul Scheerbart (1863-1915) was also a visionary architectural writer and inventor engaged in avant-garde circles. For more than twenty years he wrote about his speciality: glass architecture.

His book *Glasarchitektur* was published in Berlin in 1914. The book —a minimalistic essay, a utopian text— consists of 111 very short chapters, or rather pieces composed around a single theme, aesthetically elaborated and mirroring Scheerbart's ideological and technical interest in coloured glass. He writes in the first chapter:

> We live for the most part within enclosed spaces. These form the environment from which our culture grows. Our culture is in a sense a product of our architecture. If we wish to raise our culture to a higher level, we are forced for better or for worse to transform our architecture. And this will be possible only if we remove the enclosed quality from the spaces within which we live. This can be done only through the introduction of glass architecture that lets the sunlight and the light of the moon and stars into our rooms not merely through a few windows, but simultaneously through the greatest possible number of walls that are made entirely of glass —coloured glass. The new environment that we shall thereby create must bring with it a new culture. (Scheerbart 1914 [2000: 13])

Scheerbart's aim is to make civilization better, to reform mankind in a new built society. And the newborn, the future coming is an extensive and far-reaching translucency. New construction technology connected with the decade's metaphysical interest and spiritual movements will grow to be the creative forces. This is the utopia of Paul Scheerbart.

Accordingly, his project is composed of the spiritual construction of buildings, of building up in glass materials. Not, however, in transparent glass, but in coloured glass, showering of sparks. Glass as a building material is for Scheerbart infinitely generous, a new material in possession of everything. Glass in common with light owns the possibilities. It does not moulder away.

Scheerbart writes in a pure plain even style as the actual glass. He has a good sense of humour in his texts but is serious in his project. In chapter XIII in *Glasarchitektur* he writes: "Perhaps the honoured reader apprehends that glass architecture is a bit cold. But – during the warm season the cold is quite agreeable. At all events, I venture to say that the colours in the glass have a glowing effect, perhaps a 'new' warmth streams out" (Scheerbart 1914 [2000: 26]).

Scheerbart's glass house consists of coloured glass elements. The daylight passes and filters the colours, and originates a translucent —but not distinctly transparent— impression. From the inside you can discern the outside. From the outside you can get an inkling of forms taking shape. Man is not shut in by bricks. The coloured glass shuts her off from people's view. The coloured glass also presents intimacy in the room. The city and the scenery are barely discernible. On the other hand man is left in peace thinking of the new civilization.

In the summer of 1913 the architect Bruno Taut (1880-1938) met Scheerbart in a workshop for glass painting and mosaic. They became soul mates and the next summer they collaborated on the Glass House at the Cologne Werkbund Exhibition. Taut made the design and construction, and the ideas and visions of Scheerbart soared over the building project. The dream became a reality, the Glass House was realized. Scheerbart contributed maxims and verses on glass and colour to be engraved on the façade: "COLOURED GLASS DESTROYS HATRED", "WITHOUT A GLASS PALACE LIFE IS A BURDEN" (Figure 1).

In conformity with the cathedral builders of the Gothic era Taut is creating an interior separated from the outer world. The interior space is filled with light and colour. The purpose of the Glass House is beauty. The interplay of mosaic, coloured glass, basin-water, reflex and light fills up the building. The house uncovers the architectural potential concealed in the glass material. The cupola embraces a colour-spectrum ranging from deep-blue and moss-green to golden yellow, and, at the very top, the subsiding hue of white gold. The floor is made of glass with an open circle through which the visitors can look downwards, and also walk downstairs, into a lower "room of ornaments". The middle of the lower room contains a basin, and from the basin water is streaming towards the exit. In the background of the room is a kaleidoscope, and changing patterns of coloured glass are seen. And in additional to all this: the reflections playing in the water (Figure 2).
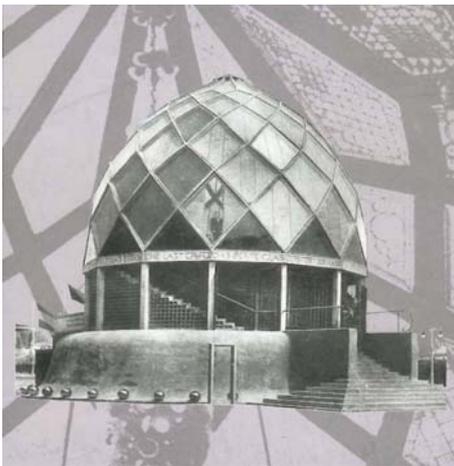
Figure 1. Scheerbart's and Taut's Glass House.

Figure 2. The interior of the Glass House.

The architects began to build of glass. Hygienics argued for interiors filled with sunshine and light. Medical findings showed a relation between architectural design and the spreading of infectious diseases. Industrial achievements gave chances to model huge glass surfaces. In 1911 Walter Gropius' factory, *Fagus Werke*, was built outside Hannover in glass and steel. Further on the architect developed an engineering in order to give the construction an expression of weightlessness. By displacing the force of gravity away from the façade it became possible to construct the whole façade as a glass surface. The Werkbund exhibition 1914 displayed Gropius' curtain-wall, fabricated of clear, transparent glass.

The glass architecture of this kind is different from the architectural ideal of Paul Scheerbart. As we have seen, Scheerbart does not count on transparency. Scheerbart, as well as Taut, looked upon glass as a material with special properties. Glass is, in Taut's words, the floating, the slender, the angular, the sparkling, the light. Nevertheless, glass was not immaterial to Scheerbart and Taut. Glass was the most airy of all materials, but still a material. Even so, one could shape glass into crystals, the highest symbols of purity and death.

Perhaps this is the appropriate place for mentioning that recently I made a visit to a couple of Oscar Niemeyer's buildings in Rio de Janeiro. The great Brazilian architect uses the glass brick wall in a rather similar way as Taut does, both in the Ministry of Education and Health and, even more remarkably, in the Headquarters of the Bonavista Bank. In the Bonavista building one can study the translucent effect of a glass brick wall, shaped like a wave, dividing the inside and the outside.

Bruno Taut's belief in the future takes along a social thought involving "a decent home for everyone", symbolically to find one's way home. His ambition was a new society socially organized. "Architecture will thus become the creator of new social forms", he wrote (Taut 1919). Taut was a forerunner talking of colour in architecture. And he was a forerunner using colour in architecture. As mentioned, Taut was inspired by Gothic architecture, just as Scheerbart was. The cathedral, in the capacity of a module of great and spiritual value, incarnates the building up, in spirit of community, of the new society. A culture for the future was conjured up in which architecture —*die Urkunst*, the Primary Art— manifests the idea in common, the social thought. In Taut's utopia Architecture replaces the Christianity of the Gothic era. Taut draws and describes small star-shaped communities spread out over the country. In these communities the cathedrals of the new era glitter in the shape of modern crystal palaces.

Taut's intention was to build a society open to people's view, to give the citizens the opportunity to obtain a clear insight into their own community. In his capacity, after the Great War, as city architect in the German town Magdeburg, Taut introduced strong colours in the façades, but he did not particularly work in glass. In a project called *Das Bunte Magdeburg*, Taut invited artists and private house owners to repaint the city. Not only buildings but also kiosks, clocks and advertisements were designed in expressionist colours (Figure 3). During his time in Magdeburg he pursued *Siedlung Reform*, a municipal housing area in Berlin, in a style so pure and plain that it offended the inhabitants. Furthermore, the colouring was so "undisciplined that it distracted the eyes" (Konstakademien 1982: 3).

At this time (the 1920's) the Hungarian artist László Moholy-Nagy taught at the Bauhaus-school in Dessau. He examined the tension and relation between light and movement, between materiality and visuality. He studied virtuality and the virtual volume. For example, Moholy-Nagy pointed out that a lighted merry-go-round revolving is virtual but also a visible volume in motion (Figure 4). His constructions of transparent materials —such as wire-netting, strainers, plexiglas, grinded panes of glass, light projections and reflecting substances— transferred the notions of tangible and non-material forms.

Figure 3. Das Bunte Magdeburg – The colourful Magdeburg.
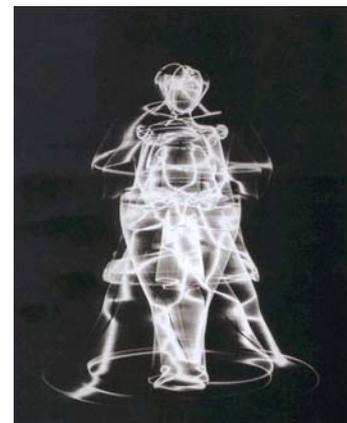
Figure 4. From Moholy-Nagy's teaching: a lighted merry-go-round revolving.

Moholy-Nagy also introduced the word *transparency* in architectural context. In architecture "transparency means a simultaneous perception of different spatial locations" (Rowe and Slutsky 1997: 23). We have already touched upon the concept of *literal transparency*, namely what is described in recent theoretical works, as "pervious to light, allowing one to see into or through a building, this was made possible by the development of frame construction and techniques for fixing large areas of glass" (Forty 2000: 286). In *Words and buildings. A vocabulary of modern architecture*, Forty distinguishes between *literal, phenomenal* and *transparency of meaning*. In his book *The new vision*, Moholy-Nagy gives a clear description of transparency in modern architecture:

A white house with great glass windows surrounded by trees becomes almost transparent when the sun shines. The white walls act as projection screens on which shadows multiply the trees, and the glass plates become mirrors in which the trees are repeated. A perfect transparency is the result; the house becomes a part of nature. (Moholy-Nagy 1947: 63-64)

In *Von Material zu Architektur*, a book published in 1929, Moholy-Nagy explicates how a new world shows itself in the growing visual culture. In painting coloured pigment is replaced by a display of coloured light. And architecture changes from restricted closed spaces into free fluctuation of forces. This alteration is especially manifested by Le Corbusier, in his strive to visually bring the scenery into the room.

Paul Scheerbart, on his part, perceived the different aspects of light, and above all, light refraction so to say powered by glass material. Scheerbart advocated translucency by means of colour, allowing light to pass through areas of glass, though not to the degree of transparency. As we have seen, this opaqueness, this opacity, gives shelter from being observed. Instead it opens up towards the scenery outside and it makes room for peace and contemplation.

Built in glass, iron and concrete Scheerbart's glass architecture is transparent in the *literal* sense of the word. The erected Glass House is in possession of a *transparency of meaning* "experiencing the luminousness of the thing in itself" (Sontag 1996: 13). But Paul Scheerbart's notion of transparency is also metaphorical, as a utopia of a new society. The metaphor indicates something different from the literal meaning, a change of use.

Perhaps is Scheerbart's utopia a challenge to our contemporary views. A challenge to our modern world built in a way (and I am now using a sentence taken from Moholy-Nagy's *The new vision*, 1947: 62) where *it is no longer possible to keep apart the inside and outside*.

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Prefabricated rolls of oil paint:
Le Corbusier's 1931 *colour keyboards*

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ABSTRACT

The creation of two colour collections by the Swiss born painter, architect and theorist Le Corbusier (1887-1965) stands out as a considerable achievement of his exceptionally remarkable career. Produced for the wallpaper factory *Salubra S.A.* in Basel in 1931 and 1959,[1] the colour collections were specially designated by Le Corbusier as *colour keyboards* —*claviers de couleurs*— in reference to the systematic arrangement of keys on a musical instrument such as a piano. Le Corbusier's 1931 colour collection can be specified, first of all, as having a strong relation to Nature; and secondly, for colour introducing a new kind of fluidity between the inside and the outside. Thereby, colour was used as a space-providing element. These observations are essential to the concept and schemes of the colour keyboards.

1. LE CORBUSIER'S FIRST COLOUR COLLECTION

Le Corbusier was granted the contract from *Salubra* in 1930 on the basis of his established reputation as a successful painter and architect.[2] Innovative in its concept of colour, the wallpaper product represented by the colour collection was itself also quite a novelty. Produced as a prefabricated roll of oil paint, the applied wallpaper was both washable as well as colour-fast with a guaranteed durability of at least five years. The same oil paint was also available in a traditional liquid form for use on door and window frames, and other lesser surface areas.

In fulfilling the commission, Le Corbusier invented a sophisticated *colour selection machine* for the company's customers. Conceived as an instrument or kind of book which could be folded and unfolded up to four times, the invention provided the user with the possibility of comparing larger colour strips with smaller colour samples as well with large colour sheets. Le Corbusier specified the colours of the different keyboards. Each colour keyboard followed a strict ordering system to enhance associative colour combinations. That is, within each keyboard, two rows of up to fourteen small colour samples were arranged horizontally in between three larger colour strips. The colour ranges of the small samples and larger strips were set up in correlation to compose the keyboard as a whole.

Possible colour combinations could be compared using a specially conceived sliding cardboard frame viewer. This system enabled the user to select up to three or up to five colours from the linear sequences in combination with a colour strip. The larger samples were intended to represent the greater surface area application, that is, the walls, and could be

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[1] The relationship between the 1931 and 1959 colour collections conceived by Le Corbusier and their reverberations in comparison with Luis Barragán's colour combinations as proposed in the abstract will be presented in a future congress or meeting.

[2] As Arthur Rüegg (1997b: 50) wrote, local artists of Basel and also the internationally known Swiss artist and architect Max Bill were commissioned to create colour collections for *Salubra S.A.*

referred to as the *tenor*. The smaller ones could be referred to as the keys or *tones* and were intended to represent the areas of lesser surface application, that is, for door and window frames, and other woodwork, niches and small architectural elements. The range of three or five different colours could be said to be a *chord*. This analogous reference to principles and phenomena of the field of music had been observed in earlier colour theories. For example, Sir Isaac Newton added two further colours to his system of five to establish a seven-colour scale, in correspondence to the equally ordered number and progression of the octave of the musical scale. As well, Louis Bertrand Castel's *colour organ* was entirely constructed on the belief that the phenomena of colour and music were analogous.

Thereby, the 1931 collection included twelve different colour keyboards with a total of forty-three wallpaper products with monochrome tones[3] and additional ones with geometric ornaments, such as dots and rhombic patterns.[4]

2. TWELVE KEYBOARDS

Looking closely at the twelve keyboards, Le Corbusier combined colours so that each colour keyboard already represented a specific colour mood, a chromatic atmosphere.[5] That is, Le Corbusier's colour ranges were tipped decisively away from so-called scientific theory. Le Corbusier's colour selection was contrived for space-defining ends, transmuting experience and observation into abstraction or to an abstract and complex three-dimensional structure of chromatic plate and slab elements. Their use in architecture was never primarily determined by the notion of decor and ornamentation, at least beginning with his move to Paris in 1917.

Considering the three large colour strips for the walls, the first colour keyboard is called 1-*Espace/Space* in which very light colours —two light blues and a greenish light hue— are specified as the correlatives of atmospheric space.

In the second keyboard called 2-*Ciel/Sky* different green-blues are associated with a notion of space referring to water, especially to the sea. Considering the three colour strips in

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[3] Le Corbusier's colours are often broken tones, especially those of the 1931 collection. In order to visualise their underlying hue, I used the colour notations of Le Corbusier's palette as provided in the edition by Arthur Rüegg (1997a). In 2001, the respective NCS colour notations were provided by the NCS Scandinavian Colour Institute at the request of Michel Cler of the Atelier Cler. Using these measurements, I conceived of a scheme to position Le Corbusier's colours in the NCS's double cone spatial diagram. This procedure was especially helpful for my analysis in order to know the basic hue underlying the light broken tones. A comparison of the 1997 edition with the original colour collections of 1931 and 1959, however, still has to be made; there are slight differences between the original Le Corbusier colours and the reproduced colours in the edition by Arthur Rüegg (1997a).

[4] The wallpapers with patterns were not reproduced in the edition by Arthur Rüegg (1997a).

[5] Le Corbusier believes in the suggestive power of words, in the forceful language of naming, going so far as to say that "once one has clearly named the colour, one can speak of a certain red with the same exactness as one would of the *A* of a tuning-fork." (Ozenfant and Jeanneret 1924, English translation by the author). Here, Le Corbusier's definition of harmony would also fit colour: "L'*harmonie*. Que ce mot semble vague! Pourtant le phénomène est simple: mettre en rapports précis des quantités exactes." (*Harmony*. How vague this word seems to be! However the phenomenon is simple: it is to precisely put exact quantities into relations) (Le Corbusier 1928 [1989: 3], English translation by the author). Usually colour naming tries to relate colour categories to the non-linguistically specified structure of our visual experience. Looking at the first *Salubra* Collection, however, the *Salubra* colour notations are represented only in numbers and are not categorized linguistically. This is, I decided to give each of the forty-three colours a name in order to grasp linguistically what is presented visually, an endeavour I did together with France Cler, colour consultant of the Atelier Cler.

relation to the fourteen colour sequences, one observes that Le Corbusier combines light blues and green-blues with earthy colours, greys, a creamy colour, and a rose and red.

The third and fourth keyboards 3-*Velour/Velvet I* and 4-*Velour/Velvet II* suggest soft beige and grey tones of materials such as raw silk, ivory, and ashes. In *Velvet I*, these colours are combined with earthy colours, reds and blues. The overall impression of this keyboard is quite different from the *Velvet II*, which takes up the rose and red, a triad of blues, but also assembles three different gradations of yellowish green, bluish green and orange. Here vivid colour combinations are integrated.

In contrast, the colours of 5-*Mur/Masonry I* and 6-*Mur/Masonry II* encompass a monochromatic earthy triad for the large surfaces, with red ochre and burnt sienna suggesting light mineral surfaces. In the *Masonry I*, the small colour samples are greens, greys, light blues, red, and a cream colour. In *Masonry II*, blues dominate, followed by greys, two light greens, red and brown.

As well, 7-*Sable/Sand I* and 8-*Sable/Sand II* also correspond to the mineral world echoing the French expression *bâti à chaux et à sable*, which means built in a solid way. The greens, greys and blue of the first *Sable I* keyboard provide a *refreshing* atmosphere. In contrast, featuring greys, blues and a whole range of reds and orange, the second *Sable II* keyboard expresses the peak of a hot day or a hot atmosphere at its zenith.

9-*Paysage/Scenery* enfolds a graduated scale of yellow-greens, which can be associated with European spring, the re-birth of Nature after winter. The spring greens in *Scenery* are primarily combined with earthy colours, reds and a grey.

The last three keyboards are called respectively 10, 11, and 12-*Bigarré/Checkered I, II, and III*. These are a kind of variations of the earlier keyboards, but entail stronger palettes. They correspond respectively to keyboard 3, *Velvet*; keyboards 5 and 6, *Masonry*; and keyboard 9, *Scenery*. Featuring grey, blue, and dark brown, one observes that keyboard 10 is associated with dense and dark materiality, and also with the manmade. For the colour sequences, earthy colours, greys and red are predominant. Keyboard 11 refers to the colours of intense minerals, such as red ochre and burnt sienna, colours, which one would only expect to encounter outdoors. As well, these ones are combined with earthy colours, greys and red. And the last keyboard, 12, relates to the vegetal suggesting the blue, ivory and, forest green of a typical western European summer landscape. For the small colour samples a variation of earthy colours, strong reds, greens, but also grey, light blues and orange are selected.

The overall impression of the 1931 colour collection is the strong presence of natural pigments:[6] red ochre, yellow ochre, burnt umbra, burnt sienna, all colours found in Nature, and red and blue, which are the very characteristic colours of Le Corbusier's early palette. The association of colours with natural elements is certainly a non-Newtonian or pre-Newtonian way of viewing colours. Castel, for instance, also defines his primary colours in relation to Nature: he wrote about celestial or sky blue, about the red of the fire and the natural or earthy yellow (Kemp 1990: 288).

This aspect is very apparent since Le Corbusier's colour collection of 1931 is derived by treating colour as a nuance of Nature and by subtly combining colours. That is, the effects include tone-in-tone combinations or a whole range of smoothly differing colours. For example, a sequence of three different blues corresponds to increasing the white or black of the same hue, as is the case in the keyboards. As well, an unusual rose tint, in fact, is a lightened-up burnt sienna, as conceived for a room of the Villa La Roche in Paris.

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[6] This is certainly a pre-condition for the "Le Corbusier-Colours" produced by the Swiss company *kt.COLOR*.

3. A STRONG RELATION TO NATURE

The influence of Nature is, in fact, continuously present throughout the development of his artistic and architectural career. In his early art education in La Chaux-de-Fonds, Nature was the point-of-departure of his art studies. For example, the form and colours of ornamental details are clearly derived from immediate observation of Nature in the 18-years old's first executed architectural commission of 1906, the Villa Fallet in La Chaux-de-Fonds, Switzerland, where he was born and grew up. A pine tree pattern applied on all surfaces of the facades has been transformed through a process of abstraction into a symmetrically and geometrically stylised repetitive motif. Concerning colour, earthy colours found in the woods, especially the yellow ochre and sienna of leaves in autumn, are combined with some spots of light blue, which enhance and refresh the overall chromatic appearance. It is interesting to observe that some years later, in 1913, this colour combination can also be found in Berlin on the facades of a housing estate built by Bruno Taut, another painter who decided to become an architect.

The importance of the subjective exploration of colour experience in the development of his life-long career was certainly demonstrated in Le Corbusier's early paintings but also in his engagement as a co-founder of *Purism*, the Parisian art movement from 1918 to 1925. As well, in the 1920s Le Corbusier's search for a relation between colour and the human body is specifically developed in his sketches. He was searching for the principles inherent in Nature. For example, blue represents the aerial and fluid, red the mineral. This colour combination blue-red is a key colour combination in his work. In Goethe's theory the combination of blue and red represented a disharmonic chord, in the sketches and paintings of Le Corbusier this colour combination is often neutralized by the achromatics: grey, black or white. These interrelations between his paintings, sculptures and architectural works are complex and will be developed in a further study. However, it is evident that Le Corbusier's colours and colour combinations are far from being theoretical, Le Corbusier's colour palettes are determined by his attachment to natural phenomena but also by the range of natural colour pigments that were available at the time.

The colour ranges of the 1931 *Salubra* keyboards can be seen as a kind of colour leitmotiv of Le Corbusier's colour practice in architecture. However, white as described in Modernist *white architecture* is completely absent in Le Corbusier's first *Salubra* colour collection. As well, there is neither black nor bright yellow nor violet. As written by Alfred Roth (1927: 36-37), Le Corbusier already applied some of his 1931 colours in his architecture at *Weissenhofsiedlung* in Stuttgart in 1927: umbra, dark grey, red ochre, light grey, rose, and a light blue.[7] As well, the use of mineral tones in the interior space is important to understand Le Corbusier's playful inversion of inside-outside. As Arthur Rüegg (1997b: 36) points out, for the first time in architecture light was invading the interior, which was now created as an open, flowing space through the free ground plan. For the first time, big glass surfaces enable light, sun and air to enter the interior. Concerning colour, strong colours which represent the mineral were also proposed for use inside by Le Corbusier.

Looking to Le Corbusier's sketches for his mother's house, red represents the sun and the earth, and is invading the interior space. Blue represents the moon but also the distant mountains, the lake and the sky, and is spreading over the interior of the outer walls. This fluidity of meaning and colour, and the chromatic interpenetration of inside and outside are

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[7] As with Alfred Roth, a Swiss architect who collaborated with Le Corbusier at Weissenhof, the symbolic meaning of colours, their psychological effect on the human being was important to him, but also "colour" as a very means of expression, as a space-providing element to enhance architectural form and volume.

extremely important in Le Corbusier's approach. Thereby, the house becomes a kind of chromatic micro-cosmos of Nature.

Summing up, Le Corbusier's 1931 colour collection can be specified first of all as having a strong relation to Nature; and, secondly, as introducing a new kind of chromatic fluidity between in- and outside, using colour as a space-defining element.

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Twelve-period seasonal colors-system

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ABSTRACT

We observed that there are no evident scientific explanations of the widespread four-seasonal methodology of color selections. Therefore, we tried to find some objectives to interpret the starting-point more precisely, in correlation with its natural origin. We completed the general classification of four-seasonal typology by adding intermediate periods. We proposed that each main period has an entering and closing part, regarding the previous or following period. Therefore, besides four main seasons, eight intermediate periods were added and finally twelve different periods of seasonal typology were classified. Such stratification is also in accordance with our meteorological calendar but not exactly with each month's diversity. Our twelve-period seasonal typology is based upon astronomical and geometrical correlation between the position of the Earth in relation to the Sun, where the Sun is the main source of the light. For this purpose we developed a special time-cycling system in which daily and yearly color-cycles are included. This system gives us an opportunity to observe the variety of correlation between antagonistic color-characteristics as well as other aspects and relationships between colors and time-cycles. The system represents a more objective basis for analysis, estimations and evaluations of trends in color counseling.

1. INTRODUCTION

The theory of seasonal colors typology was developed after Itten (1985) introduced his color-star in 1962. Spring-type is associated with light yellow undertone, summer-type with light blue, autumn-type with red and winter-type with dark blue undertone. We assume that Itten's links between specific colors and seasons are without logical explanation. Our aims are to classify colors, according to their specific seasonal appearance in nature and by adding intermediate periods to the four main seasons to create a twelve-periods seasonal colors system.

2. DEFINITIONS OF THE SEASONS, YEAR- AND DAY-CYCLES

The Sun is the main and only source of light-energy in nature and, therefore, it is most important to define seasons. There are also many other important factors influencing seasonal features: distance between the earth and the sun, angle of incidence falling to a certain part of the earth's surface (Schlyter 2004), all kind of atmospheric phenomena: thickness of the atmosphere, share of water in specific geographical zones, capacity to reflect, absorb and accumulate light, configuration of maritime regions (influencing the stream), configuration of the earth's surface (influencing air-current), humidity, electromagnetic activity of the sun, etc.

The interactions between all of the above-mentioned factors result in different shades of light and in different colors. Different light angles of incidence onto the earth's surface (Schlyter 2004) result in different quantum of light-energy distributed to certain parts of the earth, which define seasons, but differently in different geographical zones.

The geometry of geographical zones is defined according to these light-angles of incidence: the tropical zone is between angles +23° to −23°, the two sub-tropical zones are between +23° to +47° and −23° to −47°, the two moderate zones are between +47° to +66.5° and −47° to −66.5° and both polar zones are between +66.5° to +113.5° and −66.5° to −113.5°.

Though the emitted quantum of light-energy is distributed geometrical and equal along the different levels of zones, it is obvious that the shapes of the zones are amorphous, because light-energy distributed to the earth's surface is dissipated due to the influence of numerous atmospheric factors. They are able to change the distribution of light energy by up to 70% or even more.

However, geographical zones exist and they correlate directly and exclusively with the quantum of light energy, modified only by the atmospheric phenomena on the earth. No other energy significantly influences the characteristics of geographical zones and, therefore, the seasons, which are closely linked to them.

Theoretically, the geometry of geographic zones serves us by explaining any symbolic correlation between distributed light-energy into geographical zones with achromatic and chromatic color scales.

2.1 Year-cycle

The Earth in its ecliptic rail, encircles the Sun over a year and during this time creates five similar and potentially symmetrical level-positions and two extremes, which are antagonistic towards each other. The correlated levels receive about a similar quantum of light energy, extreme sides —represented by the summer and winter solstices— receive a significantly different quantum of energy. Therefore, the areas of the globe during the summer solstice receive a significantly greater amount of light energy than the areas in winter solstice, and a vice versa half year later.

Yearly-cycles (Pogacar 1994a) are also manifested differently in different geographical zones. In tropical and sub-tropical zones the differences in year-cycle are minimal with minimum changes in temperature and predominantly warm, either with dry or rainy seasons. Polar zones have predominantly winter and a short spring, where there is daylight for six months and darkness during the rest of the year. Typical changes in all four seasons are only found in the central parts of moderate zones (Figure 1).

2.2 Day-cycle

Day-cycle encompasses 24-hour-time, when the earth rotates 360° along its longitudinal axis. Day-cycle reaches its brightest point around noon and the darkest around midnight. Excluding all the atmospheric factors, we observe vertical symmetry as the 12-hour difference between the brightest and darkest points of day and night or, in other words, between symbolic black and white, where relations are also stratified in to a symbolic achromatic scale.

Specific characteristics of the day-cycles depend-on geographical zones but, somehow, they also reflect the yearly-cycle in a metaphoric way. In the tropic zone the light during the day and night is polarized to a maximum, pointing out significant differences between bright day and dark night. In polar zones, the day-cycle is minimally polarized because the daylight lasts for six months and darkness another six months. Therefore only in the center of a moderate zone is there equilibrium between day and night.

After previous description we made conclusion, that day-cycle is correlated with 12 levels achromatic scale, and the year-cycle with 12 part chromatic color circle (Pogacar 1994b, 2002).
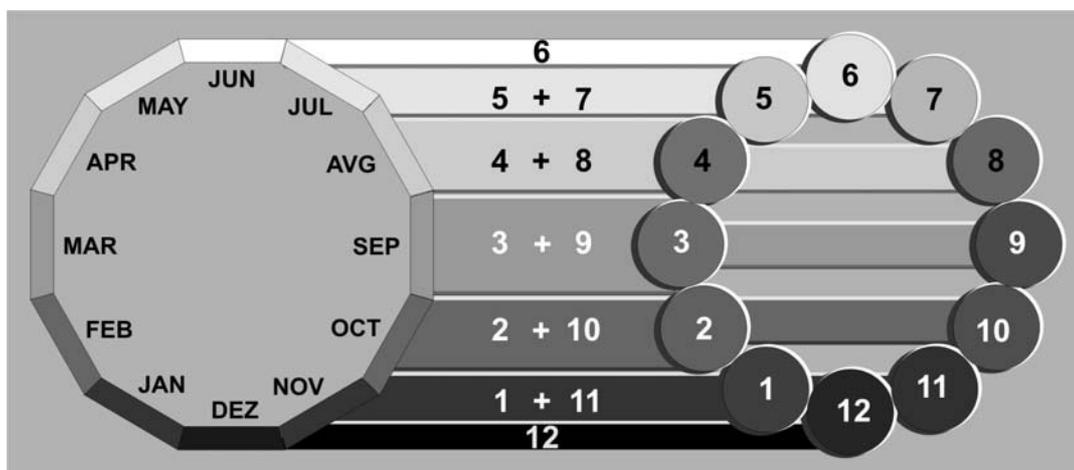
Figure 1. The year-cycle transition from 7-levels achromatic scale to 12-part chromatic color circle.

3. CREATING A TWELVE-PERIOD SEASONAL COLORS-SYSTEM (TP-SCS)

In previous four seasonal color-typology there are no evident principles for color selection and it looks like "black & white" criterion in current colored time. In addition our color-sensitivity has increased and color-measuring tools developed. To improve this system, we added eight intermediate periods, resulting in a twelve-period seasonal color system (Figure 2) (Küppers 1989).

In reality four seasons only occur significantly in moderate zone and there are no distinct boundaries between any adjacent seasons, regarding temperature or seasonal daylight. Transition from one to another is gradual.

Table 1. Basic classification of the Twelve-period seasonal colors-system (TP-SCS).

Nr.	PERIOD	SYMBOLIC NAMES	L*	C*	h
1	early- Winter	BV+B	20 - 45	20 - 40	270 - 240
2	**mid- Winter**	B+C	45 - 60	40 - 50	240 - 210
3	late- Winter	C+CG	60 - 70	50 - 40	210 - 180
4	early-Spring	CG+G	70 - 80	40 - 30	180 - 150
5	**mid- Spring**	G+GY	80 - 85	30 - 25	150 - 120
6	late- Spring	GY+Y	85 - 90	25 - 20	120 - 90
7	early- Summer	Y+YO	90 - 85	20 - 25	90 - 60
8	**mid- Summer**	YO+O	85 - 75	25 - 30	60 - 30
9	late- Summer	O+R	75 - 60	30 - 40	30 - 0
10	early- Autumn	R+M	60 - 55	40 - 50	360 - 330
11	**mid- Autumn**	M+RV	55 - 50	50 - 45	330 - 300
12	late- Autumn	RV+BV	50 - 20	45 - 30	300 - 270

Legend: B: blue, C: cyan, G: green, Y: yellow, O: orange, R: red, M: magenta, V: violet
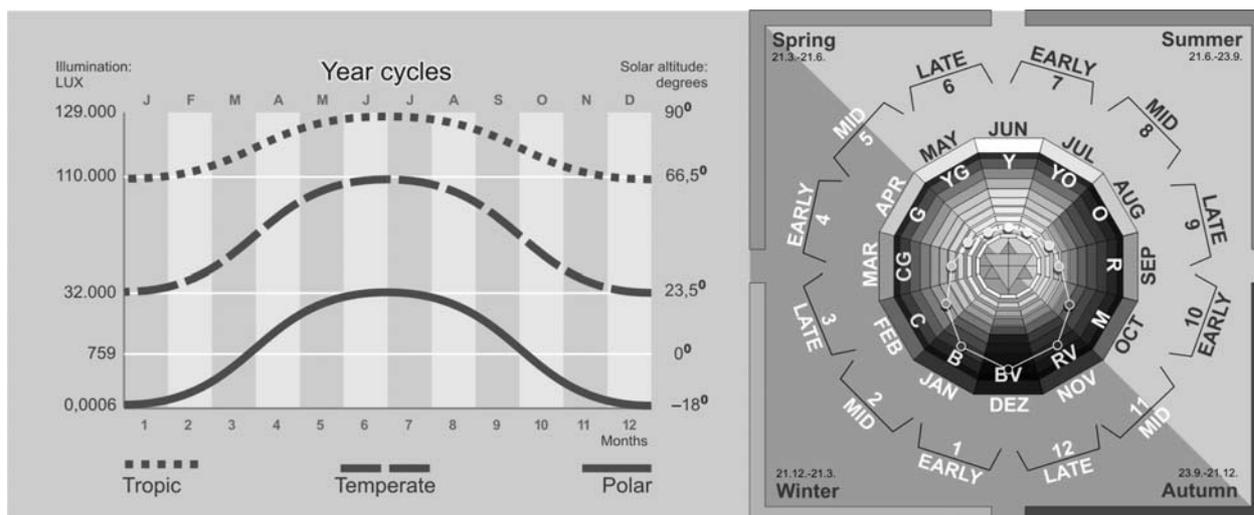
Figure 2. Example of the twelve periods course in temperate zone on the surface of a seasonal colors system body.

The entering and closing parts should have the function to link simultaneous colors together in more logical and fluid color continuum. This 12-period seasonal color system is based on geometrical correlation among CIELAB related systems (Jeler 2001) and the astronomic calendar, but not exactly with each month's diversity (Table 1) (Golob 2001). Basic colors define only color-direction in a specific period, but precise color-selection is defined along an isomorphic rail in the color body. It is important to point out that Summer-undertones, including part of late Spring and early Autumn, are much lighter from the opposite dark Winter time, late Autumn and early Spring.

4. CONCLUSION

Our aims are to improve 12-period seasonal colors typology, so as to make it a useful tool for color analysis, counseling, color-projecting and design. On the other hand, we are convinced that colors are elements of visual language and, therefore, it is necessary to participate in any development in this field. Printing invention by Guttenberg initiated unpredictable linguistic development. Computer technologies as picture-supporting tools give us today an opportunity to develop and improve elements of visual language, with color in-between.

An old proverb says that one picture tells us more than a thousand words! In the long history of visual development and perception, time has come to articulate these visual elements in order to become a vivid language and useful communication tool at the same time. Colors belong to the international communication system and often there are no words to substitute colors' abilities to speak directly without boundaries.

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Against colour globalisation.
Colour trends and colour collections: Their use as a vocabulary and effect upon colour culture

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Before entering into the subject of my presentation, I would like to ground it in a Chinese proverb about colour in daily life, which says: "The colour may be lucky or unlucky. It all depends on the context and surroundings."

In understanding and evaluating our environment, generally sixty percent of our total awareness is focused on various aspects of colour appearance. As a key to factors ranging from life-threatening to life-enhancing, colour not only serves to warn, but also to attract us. Thereby, we attribute individual colours with a broad variety of meaning and significance.

In our present era of easy international communication and transportation, the market and trade of industrially produced building materials has reached a global scale. Thereby, in proportion, the colour ranges of these materials —*colour collections*— have become major determinants in the representation of contemporary colour culture. Pre-defining the spectrum of choices available in the process of creating our global environmental, urban and habitat space, colour collections exert their influence through pre-determination. Thereby, a colour collection is far more than just a simple commercial tool. It acts as a wide-sweeping *colour vocabulary* —or *colour trend*— intended for or implying a particular use which is also imbued with concrete meanings, associations and evocations.

The concept and creation of colour collections are the result of diverse confluences or constraints that are simultaneously and dialectically launched into action: commercial, technical and construction regulations interact with the specific demands of professionals and the general public. To create a colour collection means to each time make a synthesis of these constraints. A colour collection needs to be adapted to a site and a culture, to enhance the existing diversity while providing a common mood, preserving memory, and also creating the opportunity for new colour developments. Essential elements of a vital colour collection are its legibility and the capacity to inspire the sense and experience of colour.

Showing previously unpublished material on colour trends and based upon selected colour collections of major building materials producers, the main aim of my presentation is to explore how colour collections can negatively —and positively— influence the development of colour culture. Using case studies, I will demonstrate how colour collections serve as a special kind of vocabulary belonging within a particular geographical, historical, cultural, economic and social context. Exploring how they play a dominant part in defining our world, I will show how we manage different colour policies and colour choice in the studies for creating colour trends for different companies.

The significance of colour collections is especially important to understand in these times when the word "colour" is being isolated and allocated to a solitary meaning or context. Treated as a marketing tool or kind of merchandise, the word "colour" is frequently used as just an empty abstraction, a "cover" for practices which are frighteningly reducing the immense spectrum of colour to only a very few.

Nowadays the white colour family is frequently used in developed, industrialised countries. It seems that our "chromographicness" has become quite flat, has no energy and is perhaps close to being transparent. The general reduction of range in colour collections today

can also be attributed to the effects of the expanded market and profit-optimising measures of the global economy. Today in order to economise, building materials producers everywhere are reducing their colour ranges. Impoverished, these ranges are presented as the full spectrum of what is possible, even though they disregard and fail to meet ordinary, more locally specific needs and desires of customers. Colour is thereby treated as just merchandise, not as the important measure and determinate of human well-being and giver of meaning that it is.

In limiting palettes, producers not only frustrate desire, but indirectly lead to the erosion of existing cultural traditions and eventually even to the loss of cultural memory: displaced by new appearances, traditional ways of using colour are destroyed when these colours are no longer available. Reduced colour ranges of the colour collections then of global-market directed products make it difficult to attend with care, consideration and respect to special conditions and requirements of local colour appearance which is necessary not only in urban space, but also in the sensitive context of shaping natural settings. Through different kinds of light, textures of materials, architectural forms, etc., along with other localized cultural, economical, geographical, historical, political, social, and symbolic factors, a wide range of colours are necessary to deal with colour appearance, one of the most challenging and complex elements in design.

Colour policy can also affect the colour range of colour collections. Thereby, for example, the colour policy of intentionally disregarding and erasing colour remains on architecture, e.g. decorations on facades designed by foreign groups living in the city, may lead to an insidious loss of cultural memory. As well, the adoption of a historicism which consists of preserving or reconstructing a "fake" but symbolically and historically powerful architectural or spatial appearance, can hinder new colour developments. Equally corroding, however, is the impact of global mass tourism. More and more cities are changing their colour mood and colour identity to fulfil the international visitor's exotic expectations. Thereby, the chromaticscape is expressly conceived and maintained not for citizens, but for visitors.

But when might it make sense to positively promote specific colour collections as a colour vocabulary of local culture? Under what circumstances might there be a need for their implicit introduction and use?

In designing city and nature scapes, new materials are often used side-by-side with traditional, natural ones. How can this be achieved? One important way is to employ colour. New, artificial materials often have no intrinsic colour identity and so new materials have to be given a proper colour appearance, a choice has to be made which successfully links them with tradition or the natural environment. Thereby, colour, as implied through colour collections, can help in providing a range of choices based on a study of new materials.

As well, colour collections can become important tools in maintaining and preserving indigenous colour culture, rather than destroying it. This possibility can be strengthened through setting up colour collections based on solid research, an approach which requires, however, that historical information about colour be safeguarded and easily available. Such a resource is necessary to shore up and enlarge our own limited memory. Our goal has always been to develop and extend means of supporting colour culture. The aim is to build up colour collections which correlate to the diversity of natural, traditional and new materials being employed today, as well as which correlate to the cultural, historical and social context of colour including the latest desires of colour users: the appropriate response is not to provide colour recipes, but rather to ensure awareness and the possibility to choose.

A special sub-topic of the presentation is the development of colour collections for paint or pigment powder. Originally used as an ephemeral material in religious and festive events, paint or pigment powder is one of the most poignant ways to maintain and extend colour ranges: it is the most expedient and economical way to evoke a variety of associations, the means which is most often used individually, culturally and historically to create atmosphere

and define space. Employed in a variety of applications ranging from the body to objects to interior walls and facades, the chemical components, as well as the meanings and evocations of pigment powder have varied and continue to vary with time.

Using examples from Hong Kong, the West Indies, Mexico, France, Sweden, and Moscow. I demonstrate how the colour appearance of pigment powder in these places is bound up with local, regional and national cultures in a way that is strong enough to pose dramatic resistance to the sweeping homogenisation of globalisation.

A series of colour collections or "nuanciers de couleurs," as they are called in French, has been conceived by the Atelier France & Michel Cler for different building material producers, including Zolpan (2003, paint exterior/interior), Saint Gobain Weber (2002, thick coating), IPA-Weber&Broutin (2001, thick coating), Haironville Metal Profil Belgium (2000, aluminium cladding), Ferrari Manufacturer of Membranes and Composite Textiles (1998, fabrics), Peintures Gauthier (1988, paint exterior/interior), Griesser (1983, fabrics), and Buchtal (1980, ceramics). In each of these the unique qualities and characteristics of both light and shade were evaluated in relation to the respective material. Light reveals the tactile aspects of surface, texture and colour and the interplay between shadow and light is one of the most powerful determinants of visual effect. Combining these special considerations, for example, one can generally say that iridescent colours enhance the light and reflective qualities of aluminium, while intense colours strengthen the quality of fabrics which filter light and alter shades.

As any other special kind of vocabulary belonging within a particular geographical, historical, cultural, economic and social context, colour collections play a dominant part in defining our world. Palettes change. Evolving as new aspects of colour are introduced and others discarded, some colours seem eternal or unchanging, while others seem to be more ephemeral. Colour collections are not only a space-time index in the on-going development of the spectrum of colours in use, but one of the key means available for raising awareness through general sensitisation of the eye.

By nature, colour vocabulary is immense, broad. Like words, colours appear, are extended, and then disappear in response to the flux of changing conditions. Culturally alive, colours appear and have meaning when they are used and disappear when they are no longer needed. At best, colour collections can be developed and used to ensure the abundant state of this cycle.

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Local colouring and regional identity:
Colours on buildings exterior

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ABSTRACT

The project's main thesis is to verify the existence of local colours and colouring. The research is done in the rural areas of southern Sweden at dwellings from the 19th century. The results are supposed to show the different kind of colours used and to indicate orders for how the colours were combined during different times and in various geographical areas. To find out of the local traditional colouring could be a way to strengthen the identity of regions. The introducing research had the main aim to identify geographical areas adequate to our criteria for the building objects. This resulted in four geographical areas for further investigations. The investigations have been made as archival research work, short interviews, colour steps and microscopic analyses of colour sections, which indicate presence of local colours and colouring. To be able to establish the thesis, a deepened research has to be done. Therefore the identified geographical areas will be enlarged with more microscopic analyses of colour sections, partly at new buildings in the areas but also at new building details at already investigated building objects. Through this deepened investigation it is possible to make the results more distinct and reliable. The results will further be the used to recognize orders for the colouring in the regions during the topical time. The orders of colouring will be indicated in the building objects within the project's delimitations, though the results might be applicable to new colourings for different settlements, new and historical.

1. INTRODUCTION

All built-up areas have colours. We remember and describe buildings as blue and old or for their beautiful details and even the details have colours. Our ideas about places we like are partly describe through the colours. If the colour in a well-known place or room is changed the room or place will get another character and this is obvious for everybody visiting the place. Colour is an important part of the character of a place or a room.

As an example I will mention colour research results made on the capital of Italy, Rome. When the Danish architect and colour researcher Bente Lange presented her PhD results, *The colours of Rome* (1993), everybody was not that pleased about her new idea of Rome's 18th century colouring. To maintain that this city, with its completely golden coloured facades, had during the 18th century had different light colours as light-blue, light-grey, light-green and light-red at palaces and other buildings, disturbed the idea of the colours about this worldwide known city. Everybody "knew" what Rome looked like and it seemed as a problem to accept anything else. It is easy to confirm status but difficult to accept new results. This is one example and I think it is easy to find others around the world.

In Sweden at the end of the 20th century, the local differences of colours were not that strong. New more general ideas about colouring were increasing. So the problem framing

was, did it exist local colouring during the 19th century at rural dwellings and was it the same colours and colouring that was possible to see at the end of the 20th century?

2. METHODS

It is obvious that the colours from the 19th century are not visible at all buildings from this era. Despite of that the main source to detect the colours are the existing buildings. Other sources as archives, oral sources and iconographic materials are not enough to verify the existing of local colours and colouring during the 19th century and can only be used together with the main source; colour investigations at adequate existing buildings. An important part in the beginning of the project was to identify the building objects where the colour sections could be made. How is it possible to know where to find building objects with facades covered with layers of paint containing old original colours?

Archive studies together with short interviews with building archaeologists made it possible to find areas with adequate building objects. Next step was to make ocular investigations in the suggested areas to find out if the building objects were from the delimited period of the project. Details such as the plaster, the shape of the profiles from the wooden panels and the type of nails used, determine whether the facades could contain desirable layers of paint or not. When areas with relevant building objects were defined the colour investigation could start in four separate geographic areas.

The most applicable method in this project was to make microscopic analyses of colour sections, this because of the small injury at the facades. Colour steps, the other conceivable method, makes to much injury at the facades. Of course, it is important to use a method with the lowest injury at the facade because the objects are private property. The colour sections cut out of the facades are about 5 × 5 mm and into the underlying building material. When the sections are examined the other sources are used together to make the results more reliable. The most interesting source is part of the iconographic sources: wall paintings. In one of the geographic area the wall paintings are of great interest for defining the colours at old layers of paint. Parts of the wall paintings show the facades of the farms when they were new-built (Figure 1). This has been an important part together with the colour sections in defining the original colours at the facades where the wall paintings existed.

Figure 1. Wall painting from the farm, Hemmingsmåla, Blekinge, Sweden. This wall painting shows the exterior colours of the building complex when it was new-built in 1849.

3. RESULTS

The general ideas of the colouring at traditional buildings in Sweden today can sometimes be simplified. This can be seen very clear at the results from this project. For example, at the south coast in Sweden today the farmer's dwellings are white, traditionally from white limewash. And this is an accepted idea of a typical traditional colouring in this area. But the results from this investigation present all colours but white on the facades at these dwellings. The buildings are from the middle of the 19th century and have almost similar details at the facades; it is a very well defined group of buildings. Some of the dwellings have been painted red or green since they were built in the middle of the 19th century until the 1960s, but today, after forty years, the knowledge is already forgotten.

Figure 2. This detail of a plastered facade, from a farmer's house in the coastal region of southern Sweden, shows many of the old layers of paint in many different colours.

The results from the fishermen villages in the same geographic area are totally different from the results at the farmer's dwellings. The absolutely most common colour at the facades of the fishermen's dwellings during the 19th century is white limewash. In the other geographical areas the results show the same appearing of lost contact with the original colouring. At the same buildings the most common colour at the window frames are green and it seems like it is the same colour as the boats. During the 19th century these poor fishing villages at the south coast in Sweden painted the dwellings in the most simplified way: with white limewash and rests from the paint to the boats.

The only traditional pigment produced in Sweden today is a red-oxide pigment. This is still very common at rough wooden panelling and it is a strong symbol for rural buildings in Sweden. In the southern coastal region of Sweden this pigment is not used. Therefore this area was the most relevant to make investigations about local characteristics in colouring in Sweden during the 19th century. Another aim with the investigation was to find out of forgotten local production of pigments.

One of the geographic areas studied in the project is surrounded by the common red painted facades. This area was very wealthy in the first half of the 19th century. New facades with planed wooden panelling were erected with mouldings, cornices and other costly details. Through the colour sections made at these facades it is possible to detect oil paint in light-green, light-red and light-grey. Before this period of expansion all the buildings in the region were made with visible wooden constructions and just tared or painted with the common red paint.

Another local colouring is at the island *Öland* in the Baltic Sea. The investigated dwellings in this geographic area are architectonic of the same type as the one in the previous example. The facades are developed from the 18th century's vicarage and manor houses. The main difference from the dwelling described before is that they were not panelled. Details as cornices, mansard roof and detailed main entrances were the same. A common way to protect the wooden construction was to give it a tar coating. Some of these facades were panelled in the early 20th century but it is still possible to find these building almost black from tar. From colour sections made on the facades that were later panelled it is detected that the colouring was homogeneous with tared wood, white window frames and polychrome main entrances.

Figure 3. This dwelling is from the beginning of the 19th century, with the wooden construction visible and tared. Together with the white windows and polychrome main entrance, it is a typical local colouring at Öland during the period.

4. PURPOSE AND APPLICATIONS

Of course, colouring is a process with changes over time as architecture itself, but the knowledge about the traditional colouring and perhaps of orders in how to combine colours is of great interest for the colouring of both the traditional and new buildings today. As I have tried to show, there are examples of local colouring still used and of colouring that is partly forgotten or will be in a couple of years. The main purpose with this project is to establish a knowledge about the local colouring at traditional buildings. The orders of local colouring from the 19th century show the many possibilities colour gives architecture.

Another idea is that this project is applicable at any place around the world and can make focus on the original local and regional colouring in specific places where a similar investigation can be done. To detect the local colouring makes the traditional architecture more locally characteristic and strengthen the relation to the local population.

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A model for application and analysis
of the colors in the media

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ABSTRACT

This article presents and justifies a function to color, focused on the information produced by the journalistic media, the *color-as-information*. In this perspective, a critical and descriptive analysis is made on how the use of the color, instead of contributing to the consuming of media products, has determined adhesions to ideas and goals that are out of the common intentions of the information and the communication, not to speak of some distortions, exaggerations, prejudices and other anomalies in the published news. This research presents an ontogenic instrumental model of color, with applications both at analysis as well as at production of media texts in which color is an important element of meaning. It is an orientation structure to the comprehension and use of color as information, indicating ways to the wise and responsible use or to the objective analysis of the *color-as-information* texts.

1. THE "COLOR-AS-INFORMATION"

This assignment has its origin on the concern about how society communicates using media as an instrument and how it articulates and is organized by journalism. More specifically, I have given special attention to the use of the color as information.

From a draft of a theory of colors as information (with Semiotics of Culture as basis) I search its practical application on the media —particularly on magazines, newspapers, television and the internet— trying to prove the cultural nature and its codification, that influences and is interfered by the organization of two other communication codes, besides the cultural ones: the biophysical communication codes (those from our genetic aptitude for perception) and the linguistic ones (those coordinated by arbitrarily defined rules, that are taught and learned) (Guimarães 2001).

In my latest research (Guimarães 2003), I deal with the intentions concerning the use of colors as information and I present a theoretical instrument to the analysis and the elaboration of journalistic products that use color images. I present and justify a new domain for color, leading its attention to the information produced by the journalistic media, defining it as *color-as-information*. With this approach, the research develops a critical and demonstrative analysis about how the use of color should be for the formation of an individual that consumes the media products but, in the other hand, has determined adhesions to ideologies or to finalities that do not belong to the intentions of the information and of the communication, besides some distortions, exaggerations, prejudices and other anomalies on the published news.

The idea that color may incorporate meanings to colored information increases the responsibility of the journalist and the news designer. It is important to be highlighted that the social communicator replies to the intentions that were included in the editorial guidelines, which are intentions of those who detain the mass media.

The information accuracy will depend on the history of color, on the information receptor's knowledge and on the context that is created by the presentation of the news to "push" the color

to the meaning that it is expected to form. It will always be a game between a macro and a micro-history of color, a game between permanent and temporary meanings.

What really interests me is to highlight that the journalistic improprieties are much more perceptible —that range from ideology to prejudice— when they occur on the text than when they occur in images. And even more in images (as a figurative representation) then in the use of colors. About this, the first verification I made —and that motivated this assignment— was that colors only have this power of subterraneanly add values to messages because the methods, the behaviors and the intentions in its use are not recognized by the society that consumes media.

2. POSITIVE AND NEGATIVE ACTIONS IN THE USE OF COLOR

In many relations and in various proportions between intentions and responsibilities, there are the generation of information, comprehension and formation —positive actions— and also the generation of disinformation, incomprehension and deformation —negative actions of the communication acts. Some negative actions deserve special attention:

The saturation: The amount and the intensity of colors only create conditions for the saturation of the colors, that is only definitely effected with the disentailing between colors and meanings, that is, between the colors an all the history, symbology and communication ability that they should provide. The saturation leads to the information chaos and the visual composition, as a screen or a page, and loses the ability to organize and hierarchize the information. All the elements of the composition are mixed up, and the intersemiotic richness is decomposed in the neutralization of the signification ability.

The reduction: The reduction of colors, as well as of all the communication codes, is ruled by the principle of the economy of signs, caused by the mass media.

The leveling to a minimum repertory of colors leads to immediate interpretations and bars the receptor to try (with some intellectual effort) to comprehend the chromatic universe of other cultures, of other societies, of other social layers, of other receptors, different from him. Leveled, reduced and globalized, the color no longer communicates beyond the reduced palette of signifiers and signified.

The deformation: It is the most known and contested negative action of color. Colors are altered many times in a fine way, others in an extreme way. With this altering, the original image is deformed and negative values are normally incorporated. Depending on the receptor's expectation of such information, the deformation may be well or badly received, what leads me to consider the information as being a positive or a negative action when the original information is altered, inciting the receptor to incorporate depreciated or positive values that interfere on his interpretative autonomy. I also highlight one of the positive actions:

The anticipation: Within all the overlapping combinations between the code systems used by journalism, the most influent signifier in the directioning of news has surely its origin on the color. It is possible to consider that a color brings itself forward comparing to other codes and restricts a number of signifiers taken from its repertory (storage of experiences and data about colors). Later, the other systems are received because of the repertory that was outlined by the color and only one will get to be concretized, directioning the interpretation of news. The stronger a *color-as-information* is within the repertory (mainly because of repetition), the greater will be the brevity of its memory recovery and the greater will be the anticipation on the directioning of the message.

Considering the present dynamics to the exhibition and the consume of news, the anticipation and the directioning of the information, in case it does not answer the intentions that manipulate one of the negative actions, may be used mainly to a better use of time. The reader or viewer,

immediately informed about the theme, the emphasis or about the object handled by the news, guides the comprehension effort to other codes, mainly to the oral or written verbal text.

3. A MODEL TO THE ANALYSIS AND APPLICATION OF COLORS

While the reproduction of forms and textures requires the learning for the recognition when reduced to technical reproducibility techniques, colors evoke the same biophysical actions of image reception that they would have in the natural world. Going through all the process of production and reception of images, colors may incorporate values, rules and codes that are composed of systems or semantic fields of different origins (religious, political, technical, etc.). As each code, system or field interferes directly on how color is manifested (being restricted or conformed), for several times the original linking gets shady. Anyhow, the action of color over the receptor will happen effectively, through the same channels of reception and intellection. Until some color glares with dash on a screen or on a printed page, it goes though a selective range of suitableness on the production and the reception of the information. The results of that suitableness to codes, systems or fields create layers of signification that determine the narrative structure of some communication product. Such layers are overlapped, in a way it's only possible to notice the most superficial one, while some other times the layers are so transparent that the *color-as-information* is practically analogue to the world of first reality.

If someone observes attentively the *Umwelt* in which he is inserted and tries to distinguish all the uses of colors and the "knowledges" that use the necessary data to the application and to the knowledge of the chromatic universe, he will notice the great dimension that is formed by the network of connections between all the semantic fields and the representation, reproduction and transmission systems of chromatic information. The proposed model organizes all the semantic fields in subsystems that are the "feeding sources" of the color repertory.

I defined four subsystems that will be represented later by four layers of the model, according to the similarities and differences between the semantic fields that form the color repertory.

The natural world subsystem is composed by the natural images. Not all of them, but those that emerge from the natural referents of the physical world.

In the model, *the man subsystem* incorporates the human abilities for perception, comprehension, organization and transmission of chromatic information and the way those abilities may vary in each of the groups. Mental images are also part of this subsystem.

Production subsystem: The third subsystem for the feeding of the color repertory is obtained by human production. These are all the objects created by man, who, depending on his functions and objectives, may create specific semantic fields. Some examples of semantic fields are those originated on art, on handicrafts, on industry, on fashion, on design, on the media (as a production), on the ludic and sport games, on the folklore and on the popular feasts.

Speech subsystem: The fourth subsystem is obtained by the speeches of all species, but the main speeches come from the knowledge exercises (like philosophy, science and education), the communication (as shared knowledge), the religion, the politics and the magical knowledge (mainly mythology). As speeches are diachronically, historically and geographically located, some may overlap others and even define cultural differences.

The basis to the feeding of the journalistic information is reality. Reproducing this idea, the model has as a foundation the *world subsystem* and the semantic fields that are inserted in it. The information we receive through the media was, in a way, emitted by the real world and transcodified to intelligible codes that have (or should have) the function of organizing the data for the public assimilation. The way as this transcodification takes place may be structured from the layers that are overlapped on the basis information, from the *world subsystem*. The systems and the semantic fields' participation and the levels of intervention in each one of the layers

represented by the filters will determine the result of the intermediation, projected on a symbolic system of colors. The symbolic system of colors is the sum of all the other subsystems that are put over the natural world data. It is the structured instance of a structured description of all the organization actions of the chromatic information of a fact.

Before I determine what are (from the researcher point of view) or will be (from the producer point of view) the colors that were used in some media information and the relations that form its symbolic system, the information that comes from the model layers goes through other two filters. The first is ruled by the editorial guideline and, therefore, concerns the intentions of the information acts; the second is ruled by the available resources and by the technical limitations of the chromatic information reproducibility. In the model, both filters will be considered action filters, because it is in the instance of the generation of the chromatic information that the positive and the negative actions are present.

This investigation on the backgrounds of colors is particularly important to determine what semantic fields and what behavior of the filters will be used on the color model of some culture. That is the rescue of the cultural nature of the color. It is necessary to control the specific codes of the chromatic culture of each society, if we want to analyze its application. To study the present condition of a publication implies to consider the culture of color as the result of the historic course. As culture is dynamic, some cultural texts go to the center of the system, that is, they will be in better communication conditions, while others migrate to the system periphery, where they get weaker and may be forgotten or even for not longer exist.

The participation or the non-participation of each layer (or subsystem) will determine some characteristics of the color application on the mass media, as, for example, what will be the main functions of the colored message (to inform, to select, to attach some value, to organize, to identify), what is the main semiosis environment (biosphere, sociosphere, semiosphere) and the main relations between the chromatic code signs (binarization, polarization, symmetrization), what are the main codes on the construction of the applied colors symbology (biophysical, linguistic, cultural) and what plane emphasizes the colors (expression plane, content plane). Following the model, we can also define the color symbolic system used by the mass media, identifying the participating of their resources, their technical limitations and their intentions and, at last, if we analyze the same publication during a longer time, it is possible to investigate the dynamics of the color repertory (forgetfulness because of stability).

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The experience of the painted room:
The significance of light and colour combinations

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ABSTRACT

How do various placements of painted areas affect the room? Colour is an important part of the gestalt of a building and influences significantly the atmosphere of the room. This paper presents a study, in which 280 architectural students experimented with colour and light in model rooms. In groups of 3-5 participants, they elaborated with a wide selection of room surfaces uniformly painted with several different hues and a few nuances. In their laboratory reports, the students accounted for the ways colour affected each other and how light and colour interacted. The students specially studied the perceived colour of light in the room and the colour appearance of each wall, floor and ceiling. They gave significant examples of colour effects in rooms, of shadow colours and of how complementary colours affect each other. They discussed different ways of interpreting spatial properties and the difference between experiencing the room from the "outside" and from the "inside". They also tested strategies for how to make rooms with cold and/or dim light character warmer. In the present paper, I will discuss their findings and compare them with earlier studies.

1. INTRODUCTION

Previous architectural colour research has shown the great significance reflections between room surfaces have for colour appearance and the perceived colour of light (Billger 1999a, 1999b). It has also shown how different lighting conditions affect colour appearance (Hårleman 2001). Architect students need to understand the co-operation between coloured surfaces and light, and how various placements of painted areas affect the room. They can learn principles from research. However, colour phenomena must be perceived before they can be understood. Inspired by previous research projects, we have developed colour experiments that aim to make students aware of spatial colour phenomena. The aim was also to provide tools to further explore colour, and reflect upon this dimension in students´ projects. This paper presents a one-day study, repeated 16 times with 20 first-year architectural students. In laboratory reports, the students accounted for the ways colour affected each other and how light and colour interacted.

The main driver for these studies was the students' colour education. The students' observations are interesting to present to a wider audience, because they show a wider perspective on spatial colour phenomena than usually is possible to include in more controlled scientific studies. Here, I have summarized the students' reports and discussions.

2. EXPERIMENTAL DESIGN

The students worked in groups of three to five members. Each group had one ground model (50 × 70 cm) and a selection of uniformly painted room elements (walls and floors, that also

could be used as ceilings) in many different hues and a few nuances. One side of the model room was left open. In addition to the light that came in from the open side, most groups let light fall in through holes in the ceiling. They experimented with daylight from the windows, incandescent light from desk lamps and/or fluorescent light from the ceiling. The groups were instructed to start out in a systematic way with a uniformly painted room and vary one surface at the time. Thereafter they combined the room elements freely. The main guiding questions for the investigation were:

- How do various placements of painted areas affect the room? For example, what happens when adjoining coloured surfaces meet in corners, compared to on a flat surface?
- How do the colours of the floor, walls and ceiling affect the perceived colour of light?
- How can you make a painted area more or less intense?
- Can you change the impression of depth/height/width with different colour designs?

Prior to this study the students had first studied colour combination effects in a "two-dimensional" assignment, developed by Josef Albers (1963), in which they studied contrast effects between colour samples placed together on a sheet of paper. Thereafter, they placed one or several colour samples at different depths in a box and watched them through an aperture. This assignment was developed by Lois Swirnoff (1988) and named *the window*. Contrary to the model room study, they did not study colours from inside the space. The samples were framed, which made the appearance of the coloured surfaces to become more like film colours. Observations from these studies influenced the model room study.

3. OBSERVATIONS

3.1 Effects of various placements of the room surfaces

When the students referred to colour appearance, the agreement between their perceptions was very high. However, when they discussed the experience of space, for example their impression of height, width or depth, their perceptions differed. Most students agreed that the appearance of the volume could change by varying colour combinations. There where many discussions on how two-sided a situation can be, and why we interpret individually. It seemed as the colour of the floor and the ceiling changed the appearance of height, while wall-colours opened up or closed the room. Different colours of the walls changed the balance, opened up, closed one side or changed the appearance of width.

What surface affected the other the most? The spontaneous and most common answer was the floor. The student's explanation was that in these studies, the floor was the most well lit and largest area. One group expressed that the floor affected the whole room, while a wall affected a room within the room. An example of the big impact of the floor on the room is one group's experiment with a model with light blue walls. They discovered that an orange floor made the room dark, the orange colour reflected in the shadows. A yellow floor made the room bigger, airier and warmer. A violet floor only affected the colour of the walls, and made them bluer and more distinct. A black floor made the room darker and lower and the walls kept their hue, but became blacker.

Other discoveries were that it is the *surface* that in colour, light or size contrasted the other most. Many groups noted that the back wall (the fond) was especially important, because it is in focus. Several groups experimented with black surfaces. They described that the room was experienced differently, depending on which surface was black. For example, black ceiling was more exciting, and gave a calmer and more colourful room. White ceiling, however, gave

more reflections and the room became less colourful. The white ceiling created a play with the light. Black floor increased the area, while a black fond wall caused a sense of depth.

3.2 Reflections from one surface upon another

The reports agreed with previous studies (Billger 1999a) regarding the significance that reflections have for colour appearance in a room. They described how clearer contrasts appeared in the centre of the wall, and that in a corner the coloured surfaces became more similar when reflected against one another. In the corners, the difference in colour was leveled out; the corners were more defined and a different experience of space was perceived. Complementary colours, which met in corners, annihilated each another. Common examples from the studies also showed how two clearly different nuances of the same hue, or about the same nuances of two clearly different yet adjacent hues, became equal in the room. One group described for instance how a light yellow (NCS S-0510-Y10R) and a more colourful yellow (S-1030-Y10R) became equal in a room illuminated by daylight and incandescent light. They became altogether alike when the strongest was illuminated by bluish daylight and the lighter with more yellow light.

Many students described how differently a colour combination was perceived inside the room, compared with colour samples. Four grey colours were chosen, with a tint towards red, blue, green and yellow, respectively. As small samples, they appeared grey, as individual elements of the model, they appeared slightly more chromatic. When these grey fields were put together as rooms, they got a distinctly different character. The rooms acquired more colourfulness and became for instance more red or green.

Many also discovered that the reflections could make colours, that one normally dislikes, more attractive in the right combination. The most extreme example was made by one group, which put a strong red-orange colour together with a strong green one. When the floor and the wall areas were placed beside each other on the table, the group agreed on that the combination was unpleasant. In the small model room, the striking contrast was mitigated as both the red and the green became much greyer, which gave the room an engrossing atmosphere that was found attractively ugly.

3.3 How the coloured surfaces affect the light and the atmosphere in the room

The colours of the floor, walls and ceiling affected the perceived colour of light by reflections. One can say that the surfaces acted as filters for the striking light. The students described how the light could be perceived as sharp, dull, warm, cold, saturated, etc. One group noted the light seemed less but more intense, when the walls were darker. Many pointed out that yellow not always was such a warm colour one might think, as it becomes colder in daylight. A colour became more vivid when illuminated with a light dominated by the same colour as the surface the light is shining on. Daylight often made yellow dull; in incandescent light the blue colours became gloomy. Blue got more life in daylight; red and yellow in incandescent light; green worked in both types of light.

The students concluded that it is possible to create a warm room in a gloomy or cold light situation. This can be achieved by for example making red fields on the floor in a room with light grey walls. Intense blue makes cold daylight vivid, but does not work in incandescent light, where a strong red wall works better. One suggestion to create a vivid feeling in a room was to vary the shadow-colours, through combining white with another contrasting colour.

3.4 Is there a difference to see a model from within, than look at it from outside?

There is a difference between being adapted to a light situation and stand outside looking in. Each day we experience both, as we move inside and outside buildings. It is therefore important for the model room studies not just to study the rooms from outside. The students commented on these differences and explained that if one is outside the model, one get impressions from the surrounding, and the model behave as a cupboard. There are more references and comparisons with rooms and light on the outside. Within the model however, one is surrounded by colours without disturbing factors. Several groups observed how the eye after a while adjusted such that the colours were experienced as less strong. One group described how the experience was intensified and how the colours melted together inside the model-room. The difference might depend on how long the head was kept inside the model room. After a while, one sees more variations in colour. Many described how the effect became clearer from the outside. One group found it interesting to alternate a contrasting wall in an otherwise white model room, and watch the model through a whole in the roof. Thereby they could clearly see the shadows that arose, without seeing the colour that affected them.

4. CONCLUDING THOUGHTS

It was exciting to follow the experiments of the students and to participate in their discussions. The involvement was high and often frustrating, since the task was difficult and visually tiring. It was especially rewarding to follow the students' work, since they showed an open attitude and expressed multitude and wealth of variety in their observations. A diversity that is usually hard to achieve in an ordinary research project. Despite the obvious shortcomings of the study, not performed by trained scientists in a controlled setting, the results illustrate the complexity of interior colour phenomena and open up for new questions. Furthermore, the results also show the usefulness of studies performed with students.

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Colour emotion in full-scale rooms

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ABSTRACT

A study on the emotional impact of selected colours was made. Ninety observers in 118 studies used 13 colours in two nuances. Two full-scale rooms in daylight were used with windows facing south respectively north. Dissimilar shares of skylight and sunlight causes differences in colour appearance and the question was whether these changes effect colour emotion. Furthermore, two contrary colouring methods were compared. In one method colours reinforce the light situation, in the other they neutralize it. The purpose was to investigate if these methods caused different experiences and whether one held greater appreciation. Questions are answered by analysing connections between inherent colours, compass orientations and emotional impact. The investigation showed that various colours and nuances were determinate for the emotional category. Rooms with warm colours were more appreciated than rooms with cool colours. The more chromatic nuance (NCS 1030) caused stronger emotions and different emotional categories than the light nuance (1010). Yellow and pinkish rooms caused stronger emotional effect than greenish and bluish colours, with regard to both positive and negative emotions. The colouring methods were differently evaluated. The reinforcing method made rooms with warm colours more appreciated. Warm colours where mostly experienced with joy, while cool colours were experienced with more acceptances. The neutralizing method caused higher values for rooms with cool colours in relation to warm colours. This method made south facing rooms in cool colours almost as appreciated as warm colours in north facing. Cool colours in both nuances held more accepting and less surprise than warm colours.

1. INTRODUCTION

I present a study on emotional experiences in rooms with differing colours and compass orientations: north and south. North facing rooms are lit mostly by skylight while south facing rooms are lit mostly by sunlight. Skylight is often described as cool or neutral while sunlight is experienced as warm. This causes differences in how colours appear in the rooms and between the two rooms. In colour design, colours sometimes are used to treat scarcities in the environment or to emphasise merits. In the Nordic countries achievement of an experience of warmth might be wished for. One may want to make a cool- looking room feel warm with "warm colours,"[1] but also to cool a warm-looking room with "cool colours." The method is to use a colour to modify room light, either to reinforce the light situation or to neutralize it. Others claim that room colours will be beautiful when corresponding with colour of light; blue and green colours in a north facing room will be brilliant. The aim is to gain knowledge on how these colouring methods work. The questions are:

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[1] In a recent study (Hårleman 2004) I found that the yellowish and reddish colours consistently were experienced as warm, and bluish and greenish colours as cool, bluish red and yellowish green were exceptions. Differences between these groups were consistent through many dimensions, hence use of the categories warm and cool colours.

1. Can the colour and light situation in a room cause differences in emotional experience?

2. Does the method for reinforcing or neutralizing the light situation cause greater estimated experiences than the other? Do one or another of these methods cause dissimilar experiences?

Questions are answered by showing and analysing connections between the inherent colours, compass orientations and emotional impacts. The colouring methods are evaluated in relation to their emotional impact. I will discuss my results in relation to Oberascher and Gallmetzer (2003). Indeed, they had colours with much stronger chromaticness but it might be interesting to compare results. Oberascher and Gallmetzer made an investigation on colour emotion using basic emotions[2] and various colour compositions. They found emotional associations from colours; yellow and red caused pleasure. Describing emotional quality, they found that small differences in association of concepts, or patterns of intermediate colours, can lead to dissimilar subjective representations. Red was associated to anger, pleasure and fear; yellow with pleasure and joy; green and pink with disgust.

2. STUDY DESIGN

The study is entitled the "Red-green investigation", since these elementary attributes are those primarily dealt with. In the text, however, I talk about the reddish colours in terms of "pink", since red colour in the nuances used generally is called pink. I have used the NCS system and adopt its terminology (Hård and Sivik 1981). The term *inherent colour* is used to denote that colour which an object would have if observed under standardised observation conditions applicable when an NCS colour sample colour corresponds with its notation (Fridell Anter 2000). *Identity colour* is a term which should be interpreted as the main impression of what is apprehended as a single-coloured surface in a room (Billger and Hårleman 1999). Ninety observers made 118 studies. Two similar full-scale rooms were set up in a construction cabin positioned facing north-south. Room measurements were 4.20 m × 2.90 m with similar short-end windows. The walls were roller-painted and three reddish and three greenish hues in two nuances were chosen in nuances commonly used in interiors. Nuances were 1010 and 1030. The hues were yellow-red (Y80R), red (R), blue-red (R20B), blue-green (B70G), green (G) and yellow-green (G20Y). The inherent colours red-yellow (1030-Y20R) and red-blue (1030-R80B) were also used. The observers made two complete studies in each room. These together took over one hour. The identity colour of the walls was compared with colour samples placed in a colour reference box (Billger and Hårleman 1999). The NCS notation was recorded in a questionnaire by the test supervisor. To classify emotions I used a method by the American psychologist and researcher Robert Plutchik (1962, 1980). Plutchik found eight primary emotions: fear, anger, sadness, joy, acceptance, disgust, anticipation and surprise.[3] A semantic differential scale was used. For methodological reasons I have split the (primary) emotions into positive and negative categories. The positive category consists of joy, acceptance, anticipation and surprise, and in the negative one I placed fear, anger, sadness and disgust. Data was processed in simple frequency analyses and presented as mean values.

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[2] The basic emotions (Ekman) are quite similar to the primary emotions (Plutchik) I use. Basic emotions do not include anticipation, but instead contempt.

[3] Primary emotions are emotional manifestations as most adults, disregarding culture and education are familiar with. The method has been previously used be the Swedish researcher and architect Sven Hesselgren (1987) in studies on emotions in built environment. Hesselgren used a five-graded scale while I used a ten-graded scale.

3. RESULTS

Acceptance, surprise, joy and anticipation made up the majority of reactions in the rooms. Rooms with warm colours were generally higher evaluated than rooms with cool colours. The more chromatic nuance (1030) made stronger impression and where more appreciated than the light nuance (1010). Warm, pinkish colours in 1030 nuance caused most joy and cool colours caused most acceptances. Reddish blue and bluish green caused most acceptances of all colours. Pinkish colours also caused much surprise and anticipation. The reddish yellow colour (1030-Y20R) caused the strongest positive reactions of all colours. Light greenish colours, on the other hand, caused less surprise than the more chromatic greenish colours and only weak negative emotions. North facing rooms in yellowish colours, yellowish green and yellowish red (1030-G20Y and 1030-Y80R and 1010-Y80R) was less appreciated, while the same room in the more chromatic reddish yellow (1030-Y20R) was more appreciated. Almost all rooms evoked some negative emotion, mostly disgust. Rooms with warm colours in the more chromatic nuance (1030-Y80R, -R and -G20Y) evoked disgust and anger, while the more chromatic cool colours (1030-R20B, -R80B, B70G and -G) caused disgust and sadness. Pink with elementary red hue (1030-R) caused the most negative emotions. Rooms with bluish pink caused less negative emotions than with the other pinks. Rooms with pinkish colours in the light nuance (1010) caused more acceptances and less joy than with the 1030 nuance. The former colours also evoked more sadness and less disgust.

The colouring method using inherent colours in reinforcing room- light, made the highest appreciated studies. Warm colours were higher evaluated than cool colours and higher with the reinforcing method than with the neutralizing. The neutralizing method made south facing rooms in cool colours almost as appreciated as warm colours in north facing. Warm colours where mostly experienced with joy, while cool colours where experienced with more acceptances. Warm colours also evoked more anticipation and surprise. Cool colours in both nuances held more accepting and less surprise than warm colours.

4. DISCUSSION

Yellow and pink caused pleasure and even more joy. Describing emotional quality, I found, like Oberascher and Gallmetzer, that small colour shifts can lead to shifts also in the emotional categories. Pink was associated to anger and pleasure as red was in the Oberascher and Gallmetzer study and yellow was associated with pleasure and joy. In that respect, my pink rooms correspond better with their results on red (anger, pleasure, fear) and purple (sadness, loneliness, depression). Likewise green and pink was associated with disgust, thou pink in my study, had the highest value in disgust as in joy, anticipation and surprise. This richness in variety differs from Oberascher and Gallmetzer's study, where pink merely associated to disgust. Similarly, green is not in accordance with my result. In the Oberascher and Gallmetzer study, green evoked emotions of disgust, while in my study it caused merely acceptance.

I found it interesting with the strong and differing opinions on pink. The subjects where divided in two groups, but in all cases, both groups used positive and negative primary emotions. The group with a more negative attitude towards the pink room often felt surprise or anticipation together with disgust, fear and sadness. The positive group often felt joy and surprise together with disgust or sadness. Finally, I want to discuss the primary emotions in relation to the room study. The problem is what these (primary) emotions express in such a study. I try to interpret contribution and relevance according to this study. Evaluations for surprise and anticipation were high, together with joy and acceptance. Surprise may reflect a

beautiful or astonishing impression. Anticipation may imply a curiosity towards colour and room – thoughts on how this impression can remain under the influence of daily life, and may thereby reflect a cautious prediction regarding this, or just a wish to use the same colour. The negative category is represented by strong expressions, a bit too strong to be used for anything so ordinary and harmless as the wall colour in a small and simple, almost unfurnished room. This is particularly the case with fear, but also with disgust, anger and sadness. Some observers commented on this. But still these rooms were able to evoke emotions and associations of the same kind.

5. CONCLUSIONS

The reinforcing light situations, were highest evaluated concerning warm colours, while the neutralizing light situations, caused as high values for cool colours as warm colours. The conclusion is that though warmth is preferred, the room situation can be influenced with colours. Yet, it can be seen, that although the temperature factor is important, the bluish rooms still where much appreciated.

Pale and greenish colours caused weaker emotional impact than more chromatic, bluish, yellowish and pinkish colours. This was also a question of different emotional categories, from joy to acceptance, from anger and disgust to sadness.

ACKNOWLEDGMENTS

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Painted walls:
From pictures and imitations to coloured space

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ABSTRACT

Why do people paint their rooms and buildings? Certainly there is a technical aspect, especially for outdoor painting. But, just as certainly, the technical aspect has seldom or never been the primary reason for painting. The effort to paint has risen from an urge to satisfy both human and divine needs, and from a desire to create beauty, status, illusion… In this paper I will concentrate on the non-technical reasons for painting and present six different approaches to the role of painted surfaces in architecture. These approaches I call *illusion, allusion, pictures carrying codes, decoration, spatial use of colour* and *functional colouring*. In practice these approaches are often mixed, but for the clarity of analysis I will discuss them separately.

1. PAINTING FOR ILLUSION

I will start with a building in Stockholm, dating back to the 1640's. It was built from bricks, an exclusive material used only by the church and extraordinarily wealthy noblemen or merchants. The sculptured portals and other facade decorations are elaborately cut from greyish limestone. But if we take a closer look at the brick facade, we will find that it has been painted! Bricks were not always red enough to demonstrate the uniqueness of the building, so they were painted red to enhance the impression and to boast from far away. To make the brick even more obvious, greyish stripes illustrating the mortar joints were painted over the red surface.

What we have seen here is the function of paint to create an illusion, to enhance a material, or to disguise it and make it appear as something more exclusive. This function has been relied upon in many great pieces of architecture. Italian renaissance and baroque palaces were often stuccoed and painted to look like travertine or marble. And, actually, the same practice can be traced back to antiquity.

Painted imitation of valuable stone and wood has been well developed in Sweden, as an alternative for materials that simply could not be afforded (see Fridell Anter and Wannfors 1989). In the late 19th century this art was driven into perfection, when new oil paints and elaborate techniques were developed. Paris was the centre of skill, where artisans from all Europe went to study the art of imitating marble and hardwood, and from where printed sheets and instruction books were spread.

Stucco reliefs also have been imitated by painters. The technique called *grisaille* was developed to create the illusion of a three dimensional composition through shades and lustres painted with many layers of thin paint.

2. PAINTING FOR ALLUSION

Now let us recall the red painted brick building in 17th century in Stockholm. Its pattern for colouring was echoed by a host of timber houses from around 1700. Although simpler than the magnificent city palaces, these buildings were the mansions of the gentry, and their supremacy was manifested by their colour: The timber was painted red, in a countryside where all other houses had no colours but those of unpainted timber. The act of painting in itself was a demonstration of wealth, and the choice of red was not per chance: Such a house claims relationship to the red brick buildings of the even wealthier nobility. To complete the picture, the door posts and window framings were painted grey, like lime stone, and the functional wooden details of the windows were painted ochre yellow, like oiled oak. Thus colour makes up the house into something which it is not materially, but which manifests the ambitions and social belonging of the owner. This could not really be called illusion, as hardly anybody would be fooled into thinking that this is a brick house. The function of paint is rather to create an allusion and pay allegiance to a certain social and cultural standard.

This red-and-grey pattern slowly spread through Sweden, and towards the end of the 19th century it had lost all connection to its origin as a marker of nobility and wealth. Today red timber facades with white —no longer grey— details are characteristic for farm houses and other rural buildings throughout Sweden, and in modern housing the same colour combination is used to create idyllic reference to rural life. So, the allusion to noble brick buildings has been replaced by another allusion: Today the choice of red timber facades indicates a wish to continue what is wrongly considered the original tradition of Swedish peasantry.

There is a similar process regarding the use of yellow facades. In the 18th century Swedish leading architects got inspired by the yellow brick facades of Italian palaces and by French mansions of yellowish lime stone. The brick buildings of the Swedish nobility were plastered and painted yellow, and soon also timber houses were given this new colour. In 1755 a book of pattern designs for wealthy people recommended that timber houses should be painted yellow, to achieve the status of brick buildings.

Another form of allusion is to copy the forms belonging to another craft, which is full of status but out of reach. In Swedish renaissance painting you can find various references to wood carving and artful metal work —skilfully enough made to show that you know the codes, but still not of the capacity to fool anyone that this is really the work of wood carvers or metal smiths. In the mid 19th century, when wallpaper became rather commonly spread but still was expensive, a painter could be asked to imitate the fashionable material in stencil painting —a procedure that today would cast many times more than the once so exclusive wallpaper.

But allusion need not be to a material, but could also refer to a total set-up that is favoured for one reason or another. More recent examples are the numerous pizza restaurants masqued as Italian piazzas —a frequent sight in Sweden some decades ago.

3. PAINTED PICTURES CARRYING CODES

A third approach to architectural painting is to create pictures. The choice of motives is sometimes obviously connected to the function of the building: Biblical illustrations in Christian churches serve the multiple function of illustrating the glory of God, creating an atmosphere of awe, contemplation or reflection and —in older times— teaching some religious basics to an audience which could not read written texts. But motives referring to religion and legends have also been common in homes. Such pictures were signals, showing that the house owner was a faithful Christian and a culturally developed man.

In Roman Pompeii we can find gods and goddesses in all sorts of rooms, but this should not be interpreted to prove that the Pompeiians were especially devoted to religion. Many of these divinities were the patrons of different trades, regions or even families, and the choice of for example Venus in a garden painting could tell a lot about the interests and even the political opinions of the house owner. Even more intricate are the allegorical baroque paintings, where every detail and every colour carried a message understood only by the cultural elite. Thus these paintings could carry a subtle meaning to those knowing the codes, and at the same time provide beauty and trigger the imagination and the awe of anyone who happened to see them.

4. PAINTED DECORATIONS

Pictures carrying symbolic or other meanings of course also serve an aesthetic function, as do imitations of materials or allusions to different positive values. It would seem strange to paint something —or to pay for something being painted— that you do not find beautiful. But pure decoration goes one step further, as the aesthetic function is primary. Decorations are painted just for beauty —an aim that should be seen just as legitimate as any other one.

But when we look more carefully into this it is difficult to find pictures totally void of references to values of one kind or another. Certainly many allegorical motives or imitations of costly materials have gradually lost their meaning and been transformed to mere decoration. But the most popular motives for decoration seem to be collected from nature. Animals and flowers were popular motives in Swedish renaissance, which stretches as far as 1650. Often they were painted in a naturalistic style revealing that the painter had seen the picture book of someone who had travelled far, or even a live specimen in the royal collection. Thus the scope might not be pure decoration, but also includes a wish to demonstrate cultural knowledge and societal status.

In the last years of the 19th century the international artistic movement of Jugend / Art Noveau created new styles of decoration, with explicit stress on beauty as an independent value and in expressed opposition against the symbolically overloaded heritage from earlier periods. This paved the way for wild flowers and cones into the most modern and sophisticated architecture. This can be said to be pure decoration —but the very choice of Jugend ornaments still carries references and alludes to a certain societal belonging. And similarly, the geometric patterns of the 1950's obviously pay allegiance to the ideals of the modernist movement. Pure decoration without any other implication than the aesthetical seems very difficult to find!

5. PAINTING FOR COLOURED SPACE

I already mentioned the modernist movement. But its major contribution to the use of colour in architecture was not the geometric patterns but the understanding of the creative force of colour as such. Colour without the ambition to imitate or allude, not picturing anything and not forming any decorative patterns. Just colour. This concept is demonstrated in the Dessau Bauhaus buildings, designed in the mid 1920's by Walter Gropius and with an elaborate colour plan made by Hinnerk Scheper. Here surfaces of different colours were juxtaposed in order to create coloured space. The colour defines the room and its borders, and a shift of colour most often coincides with a corner, a shift of direction. The Bauhaus school also stressed other qualities of the surface, working with alternately glossy and matte surfaces and mixing different pigments to achieve colours that would attract and fascinate in different

lighting situations. Colour is used as an independent architectural quality, co-acting on equal terms with form to create architectural space. A similar use of colour is demonstrated in Bruno Taut's housing areas from the 20's and 30's.

This use of colour, void of other meanings than those of colour itself, remained very strong throughout the 20th century building, but much too often the understanding of colour's spatial qualities were lost in the process. So, although the early modernists appreciated colour as a strong factor in architecture, it has gradually turned to something considered as outside —and minor to— the real expression of architecture. To many architects colour has become something that you can add or remove, seemingly without any noteworthy implications for the experienced spatial qualities of architecture. In my opinion, this is a total misconception, and to the general public the colour of a building or a room are often the quality most noticed, appreciated and referred to.

6. PAINTING FOR FUNCTIONAL COLOURING

The seclusion of colour from any imitating or pictorial ambitions paved the way for the use of distinctly different colours as signals. In the process often also the spatial qualities of colour were lost. This has been a common approach during the latest 50 years or so. Colour has been used to differentiate between different parts of huge housing areas, and to help the orientation in equally huge administration buildings, hospitals and education complexes. In other examples colours have been chosen according to the function of different building components in order to demonstrate the structural system of the building, or simply to facilitate industrial production by the choice of one colour for every type of unit, e.g. different sizes of windows.

7. THE APPROACH OF MULTIPLE APPROACHES

So, now we have seen six different approaches to the use of painted surfaces in architecture. But reality is seldom so simple as to be categorised with those clear and distinct limits. On the contrary, many painted surfaces include aspects of several of these approaches. But this can hardly be described without pictures, and therefore the examples will be available only to those present at my oral presentation of this paper.

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Food for thought: **The use of color in sculpture**

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ABSTRACT

This paper exemplifies the power of color in the transculturation process, to transmit and to exchange the values among different cultures in the construction of 36 public works and in the experience close to Fellows III Leadership International Developing Program, Kellogg's Foundation. The images of the works show changes in course: color in the *representative* form, color in the *implicit* way (reinforcing or contrasting the representative aspect), and color in *abstract* way, as the result. The process of direct interaction creates a new relationship type with the space and the social time: One does not work more with speeches, but with flashes and images. The art, as a tool, affects the emotion and it aids in the translation of values ethical and of citizenship related.

1. COLOR IN THE RESEARCH

Color is the primary source of life and health and every alive organism captures it. In our nature, the sun is the largest generating source of light. Without light there is no life, there are no colors.[1]

Researches mention that each color has a specific vibration, they can increase or decrease energy states in disharmony.

Will we really be able to color emotions in benefit of the health?

What does the future prepare for us?

2. WORLD OF ART AND COLOR

In art it is important to establish the contradictory!

to alert for the inexistence of absolute truths!

to present questions!

to review concepts!

The men's present time is dynamic and the speed of the transformations eliminates the verdict about something. The intellectual development does not present significant differences of perception and fruition of the color (Figure 1). However, we look for available knowledge to influence the other. Sculptures are presented as proposal for reflection. When observing the sequence of the 36 works in public space, I realized that I used color in a spontaneous way, intuitive. (This is the answer that we give when we did not discover the explanation yet, more or less as "viruses" in the area of health).

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[1] Johann Wolfgang von Goethe affirmed that only three basic colors exist: *red, yellow and blue*, of which all the other colors have theirs origin. Isaac Newton (17th century) separated the white light in the colors of the chromatic spectrum, of the rainbow, through a prism. The most different colors in a rainbow are*: red* - orange - *yellow* - green - *blue* - indigo - violet. It is interesting to remind that the white color contains and reflects all the colors, while the black color absorbs them.

The use of color in the *representative* form

Sun, 1976, Camboriú, Sta. Catarina, concrete, yellow color. Pigment in the material (Figure 2).

The use of color *reinforcing* the implicit idea

Humanity - complex relationship, 1981, marble, Washington. The white color suggesting sobriety and purity is the own natural coloration. Finished with kitchen-salt coatings to brighten the natural shine of the Carrara marble (Figure 3).

Development, 1990, Corten, Porto Alegre. The work talks about human development. Base oxide of iron, enamel synthetic white (Figure 4).

The dolphin, 1992, concrete, Imbé. The people can interact with the monument among the three concrete walls that compose the figure in the space. Acrylic and resin in the white color (Figure 5).

Veritas - truth, 2000, stainless steel, movement, MAC - Museo de Arte Contemporáneo, Puerto Rico. White acrylic for wood in the voluminous base where the sculpture rises and it moves (Figure 6).

Balance, 1979, Corten, collection of MARGS - Museum of Art, Rio Grande do Sul, Brazil. A welding drop just guarantees the stability of the work. Static balance. Paint for cars. Red (Figure 7).

Social energy, 1993, mobile, in wood, Unishoping BR 386, Lageado, Brazil. The mobile has a slow movement. Unstable balance. Special enamel paint for wood. Red (Figure 8)

In the works above mentioned, the red color —action, movement, pulse— reinforces the implicit idea of *alert*.

The use of color *contrasting* the representative aspect

Movement, 1981, bronze, BACI - Brazilian Cultural American Institute, Washington. It represents the female figure in the green color —peace, safety, trust, shelter. Copper sulfuric acid (Figure 9).

Mother of God, 1985, bronze relief, Mãe de Deus Hospital, façade, Porto Alegre. Green patina with copper sulfuric acid. The most conventional color, representing the Mother of God's dresses, should have been in blue, however for some reason, I had chosen the green instead, which reinforces the quietness of a hospital (Figure 10).

The use of color *in the abstract* of the reflected light

Prophecy - sun clock, 1996, aluminum and copper, Jardín de Escultura Internacional, UPR - Puerto Rico University. Natural color of the own material (Figure 11).

Monument to Zumbi, 1997, stainless steel, Açorianos Square, Porto Alegre. The work expresses Zumbi's ideals, black leader of the abolitionist movement. The inclined structure of stainless steel reflects the movement of the solar light and illuminates the word *Freedom,* letter by letter. The work points the man's eternal search for freedom (Figure 12).

Time and space, 1997, sun light, Porto Alegre. The people can walk over the sculpture, watching the sunshine movement on the floor pointing the four seasons, solstice, equinox. It also calls people's attention to the ephemeral of man's life and his transcendental condition. We can read: "The one that the Nature has always been manifesting is light" (Figure 13).

Memorial 1st of December against the AIDS, 2003, Porto Alegre, color reflex of the light The useful information against the AIDS are recorded in stainless steel. The sun goes through a hole and illuminates the point: December 1st. This is another educational work which stimulates the curiosity and the dialogue of social groups on prevention of AIDS.

3. REFLECTIONS ON COLOR

Nowadays one does not work more with speeches but with flashes and images, and color is the base. Color stops being just representative or the complement of a speech to be the own subject.

The analysis of some public works of Claudia Stern points us *changes in course*.

Expressing the artist's feelings, color was used in the representative form, in the implicit form and as result, already abstract.

I am trying to capture color in the purest form, the synthesis of Nature, the perception of life. Researching and looking for the scientific information, I understand to be open for new conceptions.

The energy of color is the guide for the man's new perception!

4. TRANSCULTURATION BY COLOR

I worked in several development programs. Forty people from Latin America, USA and Caribbean shared experiences of transculturation on Fellows III Leadership International Program, Kelloggs Foundation. We saw several changes of behavior in the communities observed after the placement of colorful art in public spaces. Evaluated by statistics, we noticed improvements in urban cleaning, reduction in delinquency and criminality rates. The color builds (Table 1).

By observing the colors, we are transforming our perception of the social environment.

The color emotions (Table 2).

Color is a transformation agent! Color transmits emotion.

The Occident exceeded in rules and the illogical is still there: The fights against repressed emotions destroying the whole order. Art, science and culture are getting closer, proposing new models that can rescue the hope of having a better society with more humanism for the mankind.

Color communicates (Table 3). Man always used pigment for communication rituals.[2] The color of the human skin is individualized by the natural pigment, the melanin, or the man does tattoos on himself in order to characterize his personality and his way of communication. The future will surprise us, creating chromatic proposals more and more amazing and personal features.

However, the new ethics will link us one another, differently in external aspect but unique and closer in the whole. Basically, we have to incorporate the other in ourselves because this is inherent to Nature itself: the exchange of cultures, behaviors, emotions, and gradually

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[2] The chlorophyll of the green leaves and the mineral composition from the earth as oxide of iron - yellow / red; the oxide of copper - green; the oxide of manganes - brown; the oxide of cobalt - blue...

improve a more human society. Actually, I believe in this human transformation: the metaphysics delegated God to choose us as authors of this process.

Our hands represent the tools for the recreation of this new world, expressing different perceptions of the reality, as the use of color in sculpture.

(See the figures and tables in www.artistanet.com.br).

Figure 1. Prophecy - sun clock*, 1996, Jardín de Escultura, Puerto Rico.*

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Harmonic compositions of complementary colors according to their lightness degree

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ABSTRACT

After the impact of Johann Wolfgang von Goethe's color doctrine (*Farbenlehre*) edited in 1810, and affected by his influence, the young philosopher Arthur Schopenhauer (1788-1860), encouraged by Goethe, publishes in 1816 *Über das Sehen und die Farben* (*On vision and colors*), a treatise about successive contrast and color perception along which he exposes his "theory" basically formulated by retinal activity as the answer for color stimulus. Schopenhauer proposes a numeric description for such activities related to the pairs of complementary colors, which in an uncertain time were turned into a principle for aesthetic & harmony, subject of our study and of importance for plastic and graphic arts, design, architecture, interior decoration, color communication and education.

1. SCHOPENHAUER'S TREATISE AND OUR INTEREST

Rather physiologic than philosophic, Schopenhauer's treatise refers widely to Goethe's, given the former's devotion and faithfulness towards his color theory. Schopenhauer almost entirely accepts Goethe's point of view regarding his disapproval of Newton's theory, heavily criticized in *Farbenlehre*. There were many aspects in Schopenhauer's work that Goethe did not approve of, like not assuming publicly that Goethe was his intellectual adviser, and that generated a certain distance between both. For anyone who wishes to know better these aspects, they are well described in Schopenhauer and Goethe's private letters as well as in Montinari's postface in the Italian translation of the treatise, *La vista e il colore*. Our interest is higher in the so-called Schopenhauer scale. However a few explanations should be given.[1]

It is not our intention to confront any aspect of current color theories with the ones of Schopenhauer and Goethe's time. What interests us is the concept developed by Schopenhauer regarding the retinal activity, whose degrees were later converted into a principle for chromatic harmony. The main objective of our presentation is to show how we came out with a new chromatic harmony scale revised and enlarged given a system comprised of 24 colors, that is, 12 pairs of complementary colors, while Schopenhauer's is comprised of only three pairs. We are to examine the part of the work where Schopenhauer presents his scale. From my explanation derives the following scheme:

Black, 0 – Violet, 1/4 - Blue, 1/3 – Green, 1/2 - Red, 1/2 - Orange, 2/3 – Yellow, 3/4 - White, 1

Since black and white do not represent fractions or any qualitative divisions they are not exactly colors and are not recognized as such in any time. We consider them here only as extreme ends to illustrate the question. Therefore the real color theory will have to be dealt with pairs of colors and the purity of a given color based on the exact fraction that is represented. (Schopenhauer 1995: 53)

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[1] My reading of was done with the Italian version, *La vista e il colore*. This publication derives from the translation of the 3rd ed. published in 1854 in Leipzig, revised and updated by Schopenhauer.

Schopenhauer proposes measurements referring to the retinal excitement for the three basic pairs of colors, the exact ones from Goethe's circle, with whole value being 1, split into 12 parts. In some unspecified time this scale becomes the standard to a kind of chromatic harmony applied in pictorial arts and graphic design. My knowledge of this scale came at the reading of Arnheim's *Art and visual perception*. Here we find: "Schopenhauer … directing to the complementary colors produced by post images, proposed that complementary pairs of colors happen by means of qualitative bipartitions of the retinal function. Thus red and green with equal intensity would split the retinal activity into equal halves" (Arnheim 1980: 392).

2. THE AESTHETIC QUESTION OF HARMONY

Then this Schopenhauer scale originated a system of dimensional harmony through the conversion of Schopenhauer's fractions into geometrical areas with 12 modules for each of the pairs. The aesthetic question of harmony is reached by the simple inversion of these modules where the darker color takes over the size of the lighter one to balance its application in a certain area. However, as it seems to be evident, Schopenhauer's scale has never been revised since its publication in 1816 even though there have been excellent ways to do that and to analyze retinal functions of the eyes.

In our research we made innumerable versions of it on the drawing board. But only recently we have had some success through graphic design done in the computer. Even so a sensible judgment of the visual perception regarding the color darkness and lightness is still the most used resource in the visual arts. Also the retinal bipartition, when proposed at its time, was represented with a judgment based more on perception than on any measurement made from the strict ophthalmologic point of view.

Right after the publication of the 3rd edition of *Über das Sehen und die Farben* came Helmoltz's theory that rediscovered the core of color theory developed by Tomas Young 50 years earlier, then Hering's (1878) and afterwards Ostwald's (1917), which all came to somehow confirm Schopenhauer's adroitness.

On the other hand, regarding the questions of a modern color theory —especially about the reproducibility of colors— we live nowadays a well-improved state of art thanks to new technologies digitally developed for managing colors. Such matters as primary and secondary colors along with their complementaries were thoroughly settled. Note the spectacular *Diccionario Akal del color* (Sanz and Gallego 2001): there are over a thousand pages that deal with everything regarding color. A work that would be impossible to be done without the computing technology applied in systems of design, photo and graphic editorial business.

Also, television sets and computer monitors including the *plasma* patter were only possible thanks to the solutions in color theory. Current devices can interpret in black and white colored areas of a text, photo or drawing, working with the additive synthesis of color and simulating the subtractive synthesis for graphic art processes, almost all digitalized nowadays.

Schopenhauer's original scale may be very well converted into current RGB and CMYK standards. With a few differences among certain colors and positions in the face of necessary complementarity corrections, the same scale can be designed as the following:

Black, 0 (zero lightness) / White, 1 (100% lightness) – 0 + 1 = 01 or 12/12
Green (the G in RGB) – 1/2 / Magenta (the M in CMYK) – 1/2 = 2/2 or 12/12
Cyan (the C in CMYK) –1/3 / Red (the R in RGB) – 2/3 = 3/3 or 12/12
Blue (the B in RGB) – 1/4 / Yellow (the Y in CMYK) – 3/4 = 4/4 or 12/12

Our study of a new scale of colors had many versions and we found out that we should work with absorption and light reflection values using the easiness of interpretation that computerized color management and design software provide.

3. A NEW SCALE FOR AESTHETIC & HARMONY

Another proposal of ours was to change the scale from 12 to 10 modules due to the universality of the decimal system. In fact, we created a 10-unit scale subdivided in ½ points so that it works as a 20-point scale, that is, 20 modules for each pair of complementary color.

With that we are sure to be able to formulate the rules on how to apply this principle to any pair of complementary colors. And also on how to work with tones that are not vivid colors but with any lightness and hue degrees once Cecor System has a color space that describes 2,400 colors. This is still in process with good results, only pending a final review and the publication of the work already done. For now, the visual result of the current work is shown by the figures with our tests.
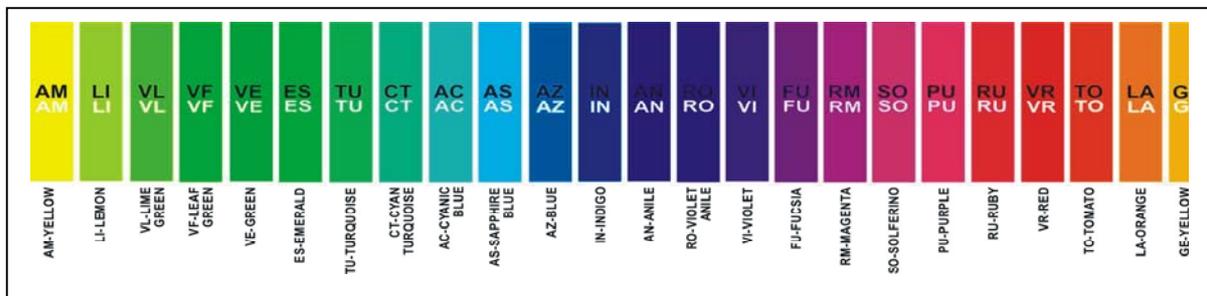
Figure 1. The 24 colors that Cecor System is comprised of, developed within the CMYK first version, with maximum saturation and lightness.
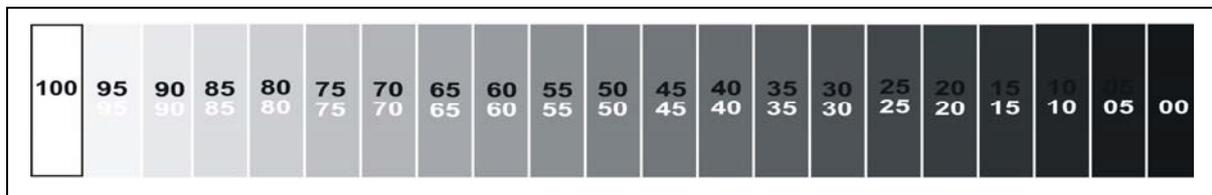
Figure 2. The lightness scale with 20 passageway points between black and white, also in CMYK first version.
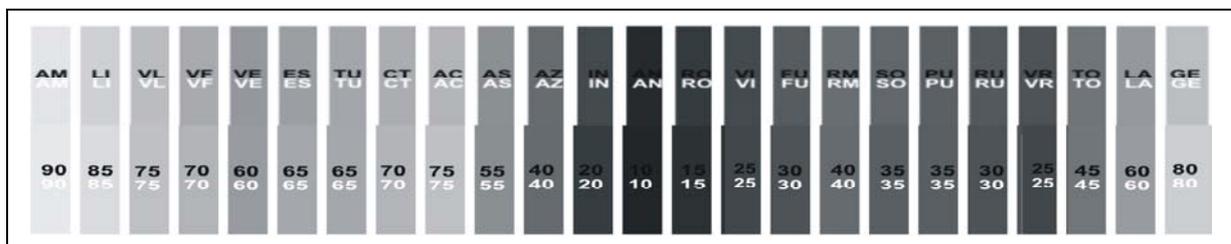
Figure 3. Above, the colored scale made in B&W with GIF bitmap processing and the lightness scale to classify each color with the best arrangement for achromatic tonalities. Some colors could have had a higher degree but some adjustments were necessary to comply with the complementary color, given that a degree of a certain color has to sum up 20 points or modules with its complementary, assuming that many colors have the same degree.
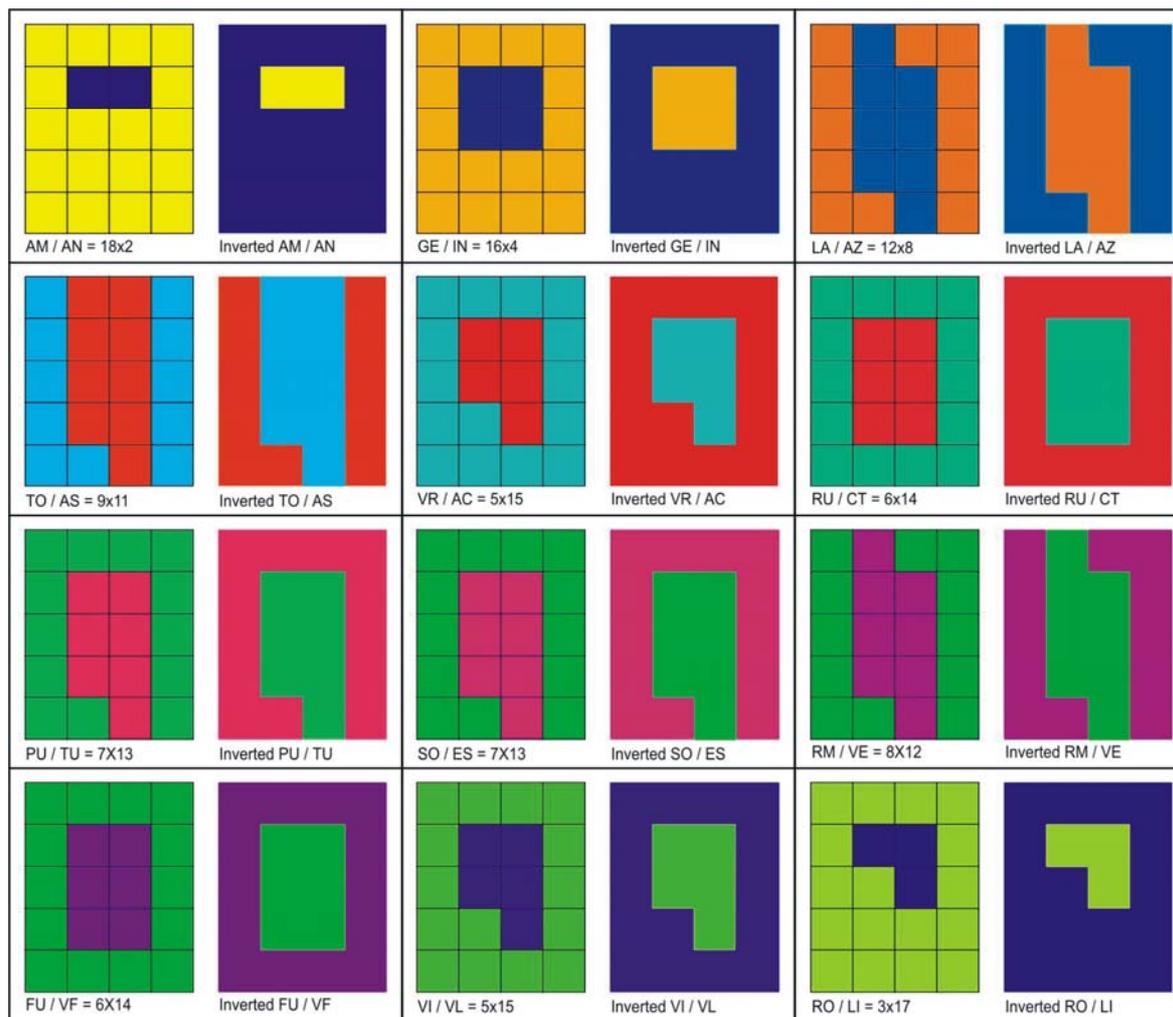
Figure 4. Comparative graphics in both normal and inverted areas with the obtained sizes for each pair of complementary colors where the relation green/magenta differs a lot from the one proposed by Schopenhauer. These are the new parameters to be adopted by Cecor System for application in elements of graphic design, architecture, decoration, fashion, etc. upon the use of complementary colors.

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Background: An essential factor in colour harmony

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ABSTRACT

Colour harmony is typically assessed using a neutral (e.g. grey) background, but little is known about the effect that background colour has on the perception of saliency and harmony. A series of experiments has been conducted to assess the effects of lightness, hue angle and chroma difference on observer perceptions of saliency and harmony for an array of single and dual foreground colour patches viewed against numerous backgrounds.

Experiments enabled observers to cluster perceptions of saliency and harmony as a function of variable background colour based on a 5-point semantic-differential scale running from a strongly harmonious to strongly disharmonious continuum. Results indicate that each background colour has the potential to create either high or low saliency and harmony ratings depending on the specific foreground colour/s viewed against it. This suggests that background colour is intimately linked with observer perceptions of saliency and harmony and should be seriously considered in future work as a further dimension and determinant of colour harmony.

Results seem to raise questions on already existing 'harmonious' colour combinations that have been proposed to date. With a simple change in background colour, the possibility of creating a *disharmonious* from a formerly termed *harmonious* combination seems highly likely. The reverse holds true.

1. KEY TERMS & INTRODUCTION

Fairchild (1997) defines *background* as the environment of the stimulus, extending for about 10 degrees from its edge, in all, or most directions. Alternatively, the background can be defined as the area immediately adjacent to the image.

Kuehni (1990) states that the word *harmony* is derived from the Greek *armonia*, meaning fitting together, a joint, concord and/or in agreement. Burchett (1991) says that when two or more colours are seen together to produce a satisfying affective response, they are in harmony.

Many studies including the works of Garau (1993), Itten (1961), Wong (1987), Birren (1961) and Kobayashi (1990) have been carried out in the past on schemes of colour harmony, proposing various rules for the relative harmony of a small number of colours viewed in ensemble. These have usually been investigated in a particular design context, but in most cases little attention has been paid to the influence of background or viewing conditions on the selection of colours. The result usually has been that sets of colours that look harmonious, or produce a particular emotional response, on a standard background such as white or grey, tend to look quite different when seen against a different background. No study has apparently been made of colour *disharmony*. The effect of simultaneous contrast has been studied by Luo et al. (1995) in terms of the changes of colour appearance of a test colour when seen against a coloured background.

2. EXPERIMENTAL SET-UP

This experiment investigated the influence of background colour on the degree of colour harmony or disharmony perceived in a group of colours. The assessment was made by observers in two ways: (a) by estimating the saliency attribute of colour, and (b) by subjective judgements of assessing the bipolar scale of harmony and disharmony. The experimental test colours were chosen based on results obtained from a mini-supermarket survey of background colours used in packaged products.

In the first experiment, single colours were presented to observers as square patches of surface colour in a large viewing cabinet using D50 illumination. Two sheets of uniformly coloured card were used to create a large background area against which observers made their judgements. Observers were asked to assess each of 16 test colours (black, blue, brown, cream, gold, green, grey, lime, orange, pink, plum, purple, red, silver, white and yellow) in two ways: (a) on saliency (b) in terms of how harmonious or disharmonious the 16 colours appeared against each background. Subjects were responsible for mounting each colour patch to a central viewing point against each background as seen in Figure 1.

Figure 1. Experimental set-up 1.

Figure 2. Experimental set-up 2.

In the second experiment, colour pairs with the highest and lowest aggregated harmony scores derived from experiment 1's findings formed the 22 harmonious[1] and 8 disharmonious[2] experimental test pairs. Each observer was asked to assess the degree of harmony or disharmony for each colour pair against all test backgrounds. The experiments were conducted using the same 12 (male and female) observers with an average age of 33. Two 30-minute sessions allowed all foreground colours to be viewed against all backgrounds under test.

Matrices with summated observer responses for saliency and harmony were made. A statistical correlational effect between aggregated observer ratings for saliency and harmony was made using Pearson's product moment correlation matrix against variables of lightness, hue angle and chroma differences.

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[1] Pink & grey; red & yellow; cream & plum; grey & black; blue & white; brown & cream; blue & cream; pink & plum; grey & purple; pink & purple; yellow & white; lime & white; yellow & grey; cream & yellow; orange & cream; white & orange; white & pink; yellow & grey; black & lime; green & white; white & red; plum & grey.

[2] Plum & blue; brown & blue; white & cream; pink & green; orange & green; green & plum; blue & red; plum & red.

3. RESULTS

Results suggest that background colour dictates overall observer judgements of what is perceptibly salient and harmonious for both single and paired foreground colours. The role of lightness difference, lightness contrast, hue angle and chroma difference does not affect saliency and harmony ratings in a defined way, but is specific to the foreground/background colour pairing.

Black and gold were the top background colours in promoting saliency, with the former attaining high saliency ratings for 11 out of the 15 foreground colours viewed upon it. Pink and silver were at the bottom of the table of backgrounds promoting saliency. The most stable background colours are pink and yellow, with plum and purple at the bottom of the stability table.

13 of the 16 background colours attained 100 % observer agreement for saliency with a good number of foreground colours. This suggests that each background can create high saliency ratings when viewed in conjunction with the appropriate foreground colour.

In general, any given foreground colour's complement (based on the colour wheel) together with those adjacent to the complement have the potential to create high saliency ratings. On the contrary, a foreground colour's analogous pair or those from a similar hue group have the lowest saliency effect.

On saliency for each foreground colour viewed against all backgrounds, results indicated that lightness difference had the greatest impact on gold, cream, black, plum, white and purple. It was noteworthy to observe too that lightness contrast values at 0.5 and above attained 100% observer agreement regarding saliency ratings.

The hue angle difference effect on saliency for single colours against all backgrounds had high correlation coefficients for red ($r = 0.83$), silver ($r = 0.77$) and green ($r = 0.75$), with the first two yielding a polynomial line of best fit. Chroma difference had no apparent effect on saliency ratings for any single colour viewed against all backgrounds.

On backgrounds promoting harmony, white, grey, yellow, black and cream had the highest observer aggregated scores. Without the inclusion of yellow, it is clear to see that these colours are of a neutral nature. The worst backgrounds in promoting harmony for all foregrounds are green and red. Black and grey seem to be the most stable backgrounds in promoting harmony for all foreground colours, while pink and plum on the contrary were the least stable.

On lightness difference, red as a background had the highest correlation coefficient of 0.81 for harmony with all foreground colours. Hue angle difference did not have a significant effect on backgrounds, while chroma difference effect was best seen for a pink background with a negative linear coefficient of −0.84.

Lightness difference had the greatest effect on the foregrounds of blue and purple seen against all backgrounds. Lightness contrast had good correlation coefficient values for blue ($r = 0.81$), brown and plum ($r = 0.73$). Hue angle difference and harmony rating clearly signalled a positive linearity for a silver foreground ($r = 0.79$).

On ratings of colour pairs, the top 13 are all combinations with white or cream, followed by those with grey and black, whilst at the bottom are the pairs made up of two non-achromatics. To demonstrate how a change in background colour affects harmonious and disharmonious pair ratings, white & cream (a formerly disharmonious pair) rose to a higher position in the table of aggregated totals for colour pairs viewed against all backgrounds, while grey & brown formerly classified a harmonious pair sunk to the bottom end of the harmonious colour pair table.

Regarding background colours promoting harmony for the test colour pairs, the neutral colours of white, cream, grey and black produced the highest aggregated harmony scores for most foreground pairs, while blue and green yielded the lowest aggregate scores. The most stable background colours in promoting harmony for the test colour pairs are white, cream and black, while blue and purple are the least stable in promoting harmony for the colour pairs.

4. DISCUSSION AND CONCLUSION

It therefore seems conclusive to state that a change in background colour considerably affects the appearance of single and paired colours with regards to saliency and harmony ratings. Lightness, hue and chroma differences between foreground and background colour affects saliency and harmony ratings for some but not all colour pairs. The overall degree of harmony for colour pairs is determined by the background colour upon which the colour pair is viewed.

With this knowledge, it is interesting then to question the extent to which proposed *harmonious* colour combinations viewed against neutral backgrounds maintain their validity when viewed against other background colours. It is suggested that background colour be considered in future work related to colour harmony.

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Color proposal for two educational buildings in Valdivia, Chile

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ABSTRACT

The chromatic decisions that architects make in their work have different meanings in their origin, depending on their own architectural vision and on the projects variables. In this paper I will present two educational buildings property of the Universidad Austral de Chile, designed by an architecture firm with the advise of a designer and a bio-climatic engineer. One building is covered with pre-painted panels selected from the Hunter Douglas color card. The other one, built in fibrocement and concrete, adjusts its coloring to a paint manufacturer's color card. Both buildings colors studies work both as a bio-climatic element due to their insulation design and to different local color studies. These buildings distinguish themselves from the local architecture due to their daring color design, which is applied also in contemporary architecture.

1. INTRODUCTION

The architects Roberto Martínez and J. M. Biskupovic have been commissioned by Universidad Austral de Chile the design of two educational buildings, financed by state funds, under the MECESUP project (Quality And Equity Improvement in Higher Education). This assignment is registered under the new policies of the university, which is constantly searching for new ways to improve its education. The buildings *Multimedia building* and *Students Aid building* were designed under the prism of these architects who have very important projects in the region, and are concerned, among other issues, especially about the election of color in their buildings, for which spatial and bio-climatic studies are entrusted.

2. MULTIMEDIA BUILDING

A symbolic building is ordered to shelter the information and communication technologies of the Faculty of Engineering Science. Miraflores Campus, which houses this Faculty, is at the end of the historical street called General Lagos, which has an extension of 2 lineal kilometers and gathers a great number of houses and warehouses that are typical of German Architecture of the late 19th century. It was then thought that the building should contain, in its formal origin, elements of this kind of architecture. These large warehouses were recognized as "formidable neutral bodies, containers of workforce", and the galleries as "showcases of the pleasure of living". It was also important to add the architectural concept as a medial theme. For that, the pixel was used as a graphic mean with which we designed the covering of the warehouse (large barn-like houses), as a huge pixeled shell. The chromatic atmosphere of this pixelation is originated in the study of color of the old rusty barns (warehouses), architectural reminiscences of Valdivia's riverside. For the gallery, an intense saturated color was used to

create a contrast between the transience of the coming and going of leisure. The Multimedia Building is conformed by two elements:

- The barn: An ocher pixeled archetype, which has classrooms and laboratories.
- The gallery: Narration of the public chores of the building.

Belonging to the Faculty of Engineering Science, it has 4 floors and 1,305 m^2, and holds 6 multimedia rooms, 3 computer laboratories and offices. Built based on a structure of reinforced concrete, exterior south, east and west coating on fibrocement plates and on the north front a glass covered wall.

2.1 Study and proposal

For the south façade, three-color proposals were made. Every one of them had a study in particular. The first one consisted in doing a chromatic emphasis of the houses that faced one of the facades of the building, and extracting their main colors to use them in the pixelation as composition. The second and third proposal, were based on a study sketched by third year architecture students, using the range of light blues from neighborhood houses and also the range of ochers from the rusty warehouses. Four colors were used in each proposal, with which a design was repeated in series on the façade forming a homogeneous texture over the fiber-cement panels. Finally, the ochre façade, corresponding to the rusty barns, was used. In both facades, the national chromatic chart of Ceresita, which has 3,200 different shades, was used.

2.2 Bio-climatic

On the north façade, the glass gallery generates abundant solar entry in the winter, and warms up the thermal mass of the warehouse, encouraging the use of a conventional heating system. In the summer, the use lattice and the well use of the shade of a small park, reduces the solar radiation in the interior of the building. There were no chromatic restrictions for the ochre façade, because it faces the south. Acoustic and electric engineers calculated the natural source of light and the interior lining, while trying to keep accurate figures for the job's requirements.
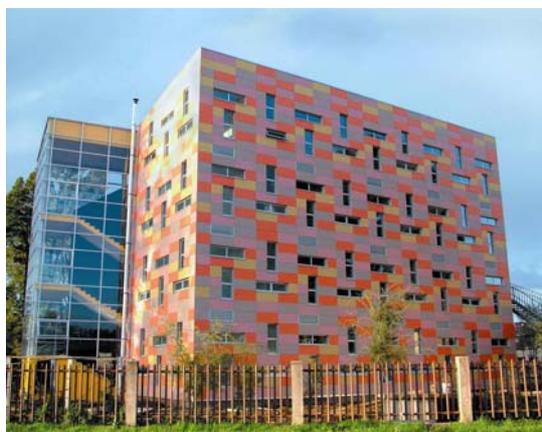
Figure 1. The ocher façade of the Multimedia building.

3. STUDENTS AID BUILDING

Belonging to the Students' Aid Directory, it is a two-story building, which withholds 6 multimedia classrooms, offices, an outdoor study area and an office for medical assistance. The exterior structure is based on wood laminated porticos, with a pre-painted steel Hunter Douglas covering, 45 cm wide. The city of Valdivia, that is 450 years old, has different basic archetypical forms, which are represented in each period by different architecture. The cylinder was used, in this case, which in the history of the city has been manifested in several ways:

- The fortified tower of the Spanish conquest period.
- The silos of the German colonization period.
- The water towers of the industrial era in the 40's and 60's.
- The cultural cylinder, today as a University City.

3.1 Study and proposal

Because of a non-written norm of the University, all the institutional buildings are light yellow and light brown, with red roofs. In this building that belongs to the students, there was a wish to not follow the traditional colors used by the "institutionalism". Photographs of the place were taken to identify 4 important color areas, because of its spatial presence: The sky and the ground (blue-gray), the vegetation (green), the buildings (light yellow) and its roofs (red). A chromatic emphasis was given to the area, which were located in the chromatic wheel. As a way of identifying with youth, its complementariness was chosen. The result was: blue-gray / yellow, green / pink, yellow / purple, and red / green. That is to say, we work with yellow, pink, purple and green. With these colors, a lineal series was built which was repeated until forming a homogeneous texture. We took the liberty of changing the saturation and brightness of these shades, according to our criteria, taking into consideration the environment's natural light, and the bio-climatic factors. A 120-colored chart, from Luxalon was used, and it gave out the steel plates with a definite pre-painted color.

3.2 Bio-climatic

To assure a pleasant temperature in the summer, it was necessary to choose shades which pigmentation would not risk overheating the tin with the sun. For this choice, an array of different colors from the Hunter chromatic chart were exposed to a noon summer day's sun radiation for a 2 hour period. Afterwards, the temperature of the samples was taken, and the colors that did not overheat were chosen. A "sub-chart" was then created, with light colors, among which the four colors that the environmental study had picked were chosen.

Figure 2. The Students Aid building.

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Studies on the exterior color of store:
Effect on the motive of entrance to a clothing store

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ABSTRACT

The effect of color and its combination on the motive of entrance to a clothing store was investigated by the experiment. Eight tri-color combinations used for the experiment were chosen from the image scale for color scheme proposed by NCD (Nippon Color & Design Research institute Inc.). The stimuli used were illustrations of storefront and were colored by the tri-color combinations. A computer system with twin display was used for indication of the two model stimuli chosen randomly from the eight stimuli. The experimental subjects select one that she wanted to enter more strongly. The motives of entrance to the model stimuli were calculated by the Thurston's method of paired comparison.

It became clear that the motives of entrance correlate with the clear – grayish values proposed by NCD. By multidimensional scaling analysis, the effect of the clear – grayish values are indicated as the first dimensional variable, and the warm – cool values are as the second one. On the other hand, the motive of entrance to a store is effected by the image of the color combination in order of the image of warm > cool – soft > hard. The result obtained by the experiment, therefore, supports the usefulness of the image scale for color scheme proposed.

1. INTRODUCTION

In a store design, the exterior of a store is the very important factor which determines the first impression that influences the sales. Also from the view point of environmental design, harmony with the color of a store and the surrounding areas is desired (AIJ 2001).

In this study, the effect of color and its combination on the motive of entrance to a clothing store was investigated by the experiment. A personal computer system with twin display was used to indicate two shop model stimuli for paired comparison method (JCRI 2000) in the experiment.

2. EXPERIMENTAL

2.1 Storefront model stimulus

The simple model of clothing store as shown in Figure 1 was used, since the main purpose of this experiment is the investigation of the influence by color. The stimuli used were colored by the tri-color combinations. The
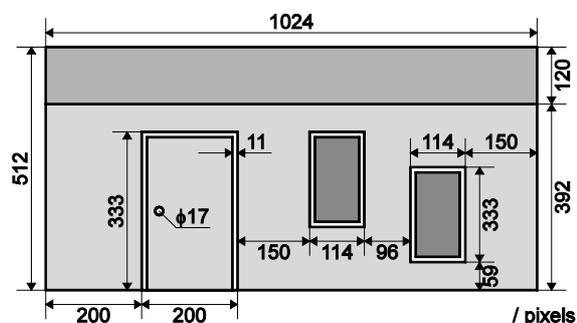
Figure 1. Storefront model used:
■; main color, ▨; assort color,
and □; accent color.

ratios of the colored regions are 70 % for the main color, 25 % for assort color, and 5 % for accent color (Kawasaki 2002).

Eight tri-color combinations used for the experiment were chosen from the image scale for color scheme proposed by NCD (2001, 1999). The color scheme was consisted by three dimensional basic image pair namely warm – cool, hard – soft, and clear – grayish. The color combinations are called by the image pattern names shown in Figure 2. Table 1 shows the image pattern names and color with their RGB value.
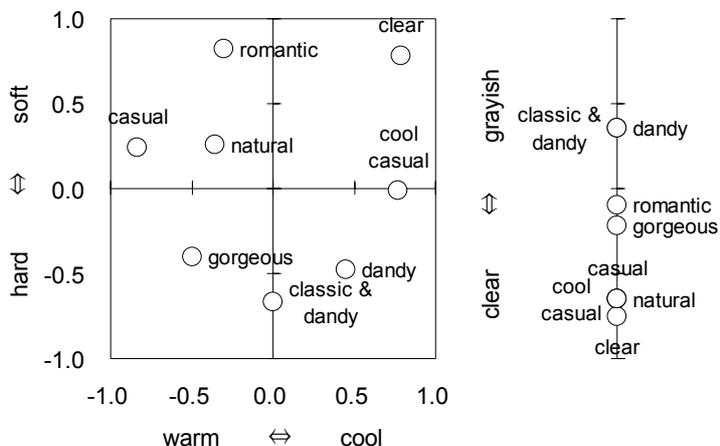
Figure 2. Used color on image scale for color coordination.

2.2 Experimental conditions

A DOS/V computer system with twin 17 inch CRT display was used for indication of the two model stimuli chosen randomly from the eight stimuli as shown in Figure 3. The computer system was set in the dark booth for prevent the external lights, and the experimental subject (n = 20,
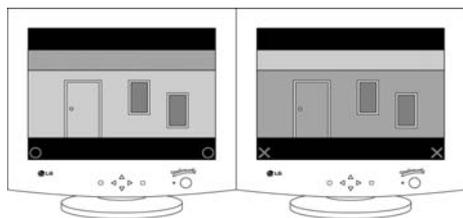
Figure 3. Example of the stimulus on CRT.
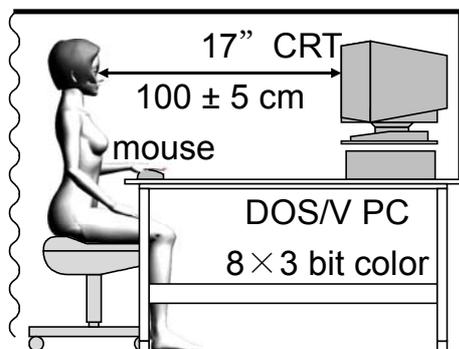
Figure 4. Illustration of the experimental environment.

Table 1. Image pattern and color used for tri-color combination.

image pattern	color	hue / tone	R	G	B
casual	main	YR/V	255	156	0
	assort	Y/B	255	216	40
	accent	B/B	91	189	206
natural	main	YR/L	232	157	96
	assort	Y/Lgr	205	191	156
	accent	Y/L	228	200	99
romantic	main	RP/Vp	255	225	237
	assort	RP/P	255	196	226
	accent	B/Vp	217	253	255
clear	main	BG/Vp	213	255	236
	assort	N9.5	255	255	255
	accent	PB/Vp	225	236	255
cool - casual	main	Y/V	255	217	0
	assort	N9.5	255	255	255
	accent	PB/V	0	33	152
dandy	main	P/Dgr	64	0	72
	assort	N8	199	199	187
	accent	PB/Dp	0	50	117
classic & dandy	main	R/Dgr	64	0	24
	assort	Y/Gr	171	157	109
	accent	B/Dgr	0	51	68
gorgeous	main	R/S	184	28	16
	assort	Y/S	209	171	0
	accent	R/Dk	104	0	31

women's university students) sat in ca. 100 ± 5 cm front of the displays as shown in Figure 4.

The experimental subjects selected one store model that she wanted to enter more strongly by mouse operation. Then the stimuli changed to another pair and the selection repeated until all the twenty-four combinations were used out.

3. RESULTS AND DISCUSSION

3.1 Analysis by the Thurston's method

The results of paired comparison method are shown in Table 2. The motives of entrance to the model stimuli were calculated by the Thurston's method of paired comparison. (Amakasa 2000) In this method the $\sqrt{2\overline{R}}$ values can be used as interval scale.

Figure 5 shows the relationship between the clear – grayish image and $\sqrt{2\overline{R}}$. It became clear that the motives of entrance correlate with the clear – grayish values proposed by NCD. However, other basic images namely warm – cool, and hard – soft image had low correlation. Their correlation coefficients were $r^2 = 0.20$ and $r^2 = 0.24$ respectively.

3.2 Analysis by multidimensional scaling

By multidimensional scaling analysis (Takane 1980), the effect of the clear – grayish basic image was indicated as the first dimensional variable as shown in Figure 6, and that of the warm – cool image was as the second one as in Figure 7.

However, the third dimensional variable had very low correlation with any basic images.

$$y = -1.14x - 0.33$$
$$r^2 = 0.64$$
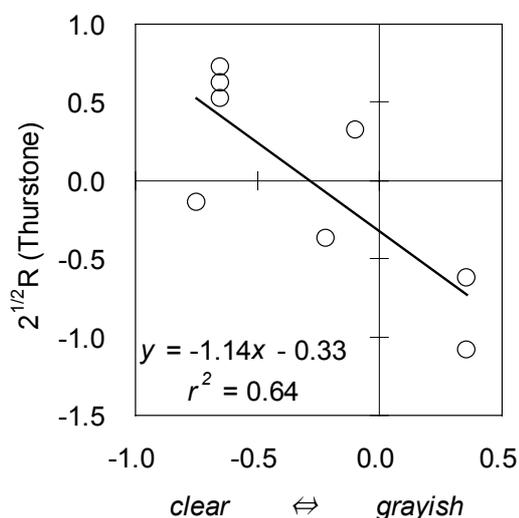
clear ⇔ *grayish*

Figure 5. Relationship between the clear – grayish image and $\sqrt{2\overline{R}}$.

Table 2. Results of paired comparison method.

image pattern	Casual	natural	romantic	clear	cool - casual	dandy	classic & dandy	gorgeous
casual	–	14	11	15	10	18	16	15
natural	6	–	14	17	10	18	16	13
romantic	9	6	–	13	11	17	13	14
clear	5	3	7	–	8	13	14	15
cool - casual	10	10	9	12	–	18	14	17
dandy	2	2	3	7	2	–	10	4
classic & dandy	4	4	7	6	6	10	–	7
gorgeous	5	7	6	5	3	16	13	–

$y = -2.23x - 0.64$
$r^2 = 0.51$
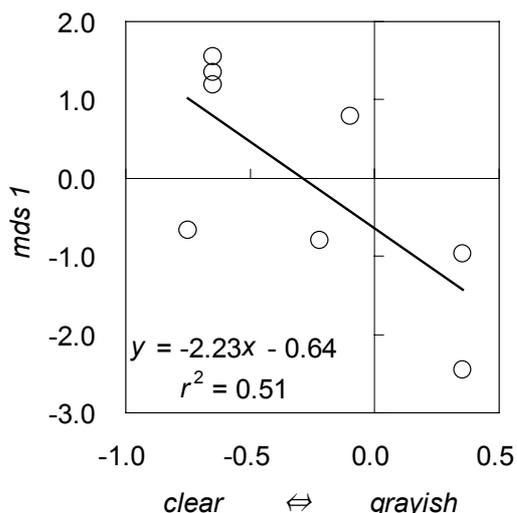
Figure 6. Relationship between the clear – grayish image and mds 1.

$y = -1.03x$
$r^2 = 0.44$
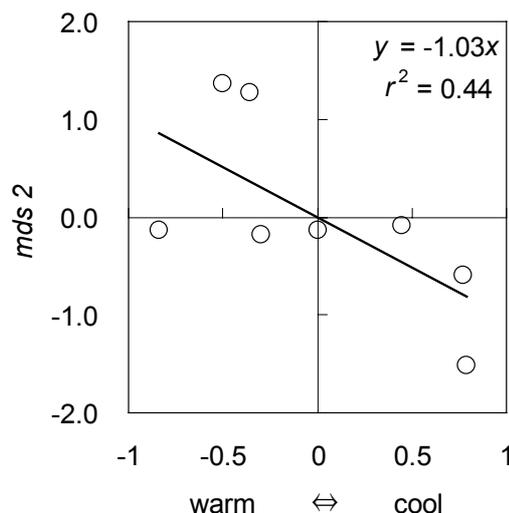
Figure 7. Relationship between the warm – cool image and mds 2.

3.3 The tendency on the image scale

The motive of entrance to a store is effected by the image of the color combination in order of the image of warm > cool – soft > hard as shown in Figure 8. The result obtained by the experiment, therefore, supports the usefulness of the image scale for color scheme proposed.
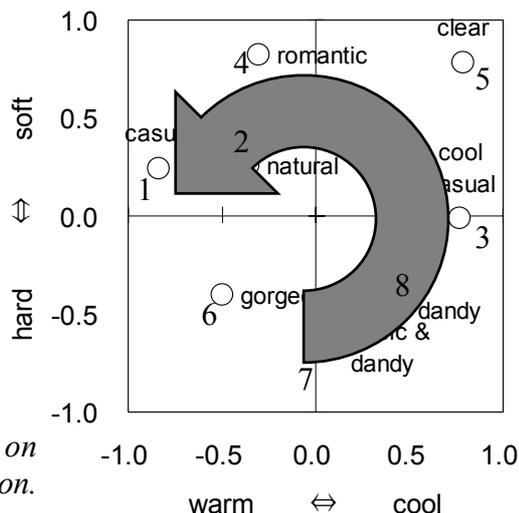
Figure 8. The tendency of the motive on image scale for color coordination.

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Colour perspectives: On colour and paint

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The purpose of my thesis (Olsson 2004), and of this presentation, is to give an outline of the current research in colour and paint, and also about previous research within the subject of colour in architecture. The survey begins with a historical perspective of the subject, and also draws an outline of the theory and practice of colour and paint as a whole. The intention is to put the Swedish colour research into a larger context, in time as well as in space. The nature of colour embraces several different disciplines: technology, science, humanistic science, arts and philosophy. Colour as a phenomenon has no distinct boundaries. By belonging to different disciplines and by closely bounding on several different areas of research, the subject is endowed with both depth and width.

My principal question is: What do we actually know about colour? This question is followed by: How is the relationship —at different times and in different areas of research— between the *visual perception of colour* and *paint as a material?* Is it at all possible to separate the visual perception of colour and the paint material from one another, without losing any vital aspects in the viewing of colour?

Colour perspectives consists of three different parts. In the first part of the survey the theoretical issues of colour are discussed, from ancient times to the 20th century. The nature of colour as both transitory and permanent has been a point of interest to philosophers throughout the years. The ancient philosophers regarded light as what makes colours visible. During the Renaissance, Alberti and Leonardo studied the relationship between light and colour. Goethe wrote in his book on colour theory that the nature of colour is that of a phenomenon.

Throughout the years, colour has been systemized in colour spaces, colour bodies and colour schemes. The second part of the survey studies how colour has been used in practice, in architecture and in space, during the 19th and 20th centuries. These two centuries are vital for how the outlook on colour has changed and how the research has progressed.

The third part of the survey focuses on today's research on colour and paint in Sweden, shedding light on the research carried through from the 1960's and onwards. The current international research is discussed in a general perspective, while the Swedish research is discussed more thoroughly. Oftentimes, the international research results form the historical platform for the Swedish research.

To the pre-Socratic philosophers there is a connection between the paint material, *the stuff*, the eye of the beholder and the four elements. To Democritus, colours do not exist unless they are physically touchable. Etymologically, the word colour has its origins in the physical paint material, as a skin that hides and encloses whatever is underneath. In today's Swedish dictionaries, colour is mainly described as a visual phenomenon. Swedish colour research has focused on visual perception. The message is that colour is what we see as colour. In its time (the 1950's), the Swedish Association of Arts and Crafts (Svenska Slöjdföreningen) gave the different colours names that were associated with the paint material.

The studies on polychromy carried out through the 19th century showed that the ancient Greek temples had been painted in different colours. Through this knowledge, colour was endowed with a new and independent role in the world of architecture. A probable cause of the importance of colour in architecture during the 1920's is that architects, as well as artists

—Bruno Taut, the Bauhaus school, the De Stijl group, Le Corbusier— actually performed artistic painting themselves. To Taut, paint was a material equal to any other building material. The Bauhaus school made no difference between artistic and non-artistic painting. The base point was that colour and paint were natural components in architecture. Hinnerk Scheper introduced practical functions for wall painting. Moholy-Nagy created a terminology to describe the structure, surface and working process regarding paint and other materials. In the new visual culture that was emerging, he combined materiality with visuality. De Stijl introduced pre-fabricated and pre-painted building elements. And Le Corbusier combined painted surfaces in primary colours with surfaces of raw concrete.

Colour and paint are principally studied from two angles: as a visual phenomenon and as a material. Colour as a visual phenomenon has long been the major line of interest to most academic researchers in Sweden. Within the area of environmental psychology, it is recognized that the aspect of colours and colouring of spaces have an effect on human beings. Within the area of architecture, the colour phenomenon is evaluated in three-dimensional studies, and it is also studied how the character of a certain colour changes in different conditions. The change in the perception of outdoor colours is studied considering factors such as distance, weather conditions, time of year and the visual angle and viewing conditions. The difference between a colour sample on a piece of paper and the perception of the colour on the façade of a building has also been studied. Current research within the area of paint as a material includes topics such as the ageing of paint, traditional paint types and material, and the concept of materiality. It also shows the problems that the modern paint materials bring, such as health hazards and pollution.

From this survey, the following thesis emerges: To capture any of the depth and width when looking at colour, both the visual perception of colour and the physical paint material have to be included.

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Colour and the design of urban image

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ABSTRACT

Colour is a tool of expression and communication which requires, on the part of designers, an updated knowledge of its scope of action. It is necessary, therefore, to understand the problems involved in the city of the end of the century, which will enable us to fully exploit its communicative and expressive potential. The research on the action of colour and its use as a tool of design of the urban image leads to the fact, today more than ever, that we have to admit that the science of colour is a science of information with a psychological and technical focus which has gained ground and has given back a referential function to colour in the contemporary city. Taking into account that daylight is the most important element that reveals colour appearance, this communication will emphasize the relationship between the changes of colour of daylight, the perceived colour of façades and the impact over the used paints. It will develop some provisional conclusions of the last researches of this team.

1. LIGHT AND THE CONSTRUCTION OF IMAGE

Some studies on light in the urban space contribute to understanding the value of light to be able to perceive the essential meaning of this space, its dimensions, the induced and produced effects, the colours, what it really is and wants to express. The construction of the urban space involves some processes such as thinking, perception, memory and behaviour, not only in the social and institutional frame of the city but also in a technical and ideological context. Any situation that allows a selection of reality, determining factor and a syntax as a manifestation of order can be considered as an image. According to Justo Villafañe (1996: 44), the construction of a model as a process achieves its purpose with the interpretation of the observer; he is the one who perceives the most important structural features of the object and elaborates a pre-iconic scheme as the beginning of the representation that ends up with the creation of the image and its following subjective valuation. In all these aspects, colour as a form or sign, plays an important role in the perception process as well as in the representation one.

The information of the perceived urban environment is codified since the human visual system is able to locate and interpret certain regularities in the luminous phenomena in the scope of sight with reference to three characteristics of light: its intensity, wave length and distribution in space.

The intensity refers to the perception of luminosity coming from the visual system reactions to the luminance of objects; this intensity is subjective, since it is an interpretation modified by psychological factors which also depends on whether it is a luminous source or reflected by them. The wavelength enables the intelligibility of colour coming from the reactions to the light lengths emitted or reflected by those objects. Similarly, this is also a subjective factor since colour is not in the objects but exists in the perception.

Finally, light permits the perception of the spatial limits of objects, their outer edges, determining in this way the boundary between two surfaces of different luminance for a definite point of view.

2. LIGHT AND MORPHOGENESIS OF SPACE

The perception of space is not only visual and in fact is essentially connected to the body and all the sensorial channels where the information flows. The experience of space is, apart from visual, tactile, kinesthetic and kinematic and its essence arises from the relationships between the perceptual modalities or visual synesthesia. This statement in the theory of design is complemented by César Jannello (1984) who considers the existence of four categories of visual systems where light plays the main role. These categories are grouped in two and depend on some common characteristics. The features are: spatial delimitation and visual or tactile textures; and colour and cesias (luminosity, brightness, softness, translucency, specular reflectiveness, opacity, diffusion, transparency, and absorption).

The spatial delimitation and the texture, apart from depending on the incidence of light, are mainly involved in the conception of space for their development and application, that is to say the three-dimensionality, being colour and cesias modified by the incidence of light and its distribution according to Jannello (1984) and Caivano (1991).

The wavelength determines the sensation of colour. It is mainly a sensorial experience, the reproduction of which requires an energetic transmitter, an instrument to modulate that energy and a specific receptor, that is to say light, objects and the human eye that transmits the sensation to the brain which interprets the colour. These three concurrent agents of the chromatic experience are highly variable and it is this mobility which turns them into a strong agent of the design of image and of transformation of experiences in the urban environments.

Natural light provides very changeable views of the same urban sector at different times of the day, in different seasons and, of course, according to the hemisphere where the place is located. Light produces an intensity of colour, luminosity and shades which change rapidly with solar incidence creating other nuances of the same hue; at the same time it generates different textures, shadows and cesias. All these factors interact in the construction of urban spaces together with the diverse ways of obtaining colour as the mixture of lights or the mixture of pigments.

From the physics perspective, light behaviour can be described objectively by means of measurements done with technical equipment; however, from the phenomenological point of view this behaviour is supported by perceptual surveys. It is therefore relevant to introduce the concepts of perceived colour and inherent colour. As Karin Fridell Anter (2000) expresses in her research based on the Natural Colour System (NCS) these concepts constitute the basic system for a chromatic survey without technical equipment.

The colour that an observer interprets in an object or field under certain light and visual situation is called perceived colour whereas the inherent colour is a constant characteristic of the object independent from external conditions; it is an intrinsic capacity of the object to produce a certain perception of colour, which, whether observed under standard conditions or not, remains invariable.

To sum up, the four interrelated visual categories of spatial delimitation, textures, cesias and colour complete the visual perception of the world, with light as the element which, depending on different conditions of observation and/or mutation, can change the appearance of the surroundings modifying their image as well.

3. DEMONSTRATION

This team of researchers studies the chromatic phenomenon and its performance in the urban environment, remarking its importance in the environment's transformation. It uses the NCS (1996) as a colour system to prove in a phenomenological way the different chromatic modifications brought about in the system in contrast to the technical survey using a luxometre. Light is a very changeable morphogenetic physical agent and due to this characteristic, it influences the visual effects of transformation, not only of the perceptual geometrical appearance but also of emerging meanings of urban environments. It is therefore essential to notice the great instrumental strength of colour in the design of urban environments. The above mentioned is verified in an area of the city of Córdoba, Argentina.

3.1 Field work

Before the demonstration of the hypotheses in the field work, it was considered important to ask Dr. Javier Hernández Andrés, member of the Optics Department of the Faculty of Sciences of the University of Granada, about the scientific aspects of light and its technical applications (see Hernández s.d.). In summary, to contrast the variations of the perceived colour with the variations of daylight, he advises the use of an spectrophotometer and spectroradiometer to know the spectral reflectance and the different kinds of daylights that can illuminate the components.

3.2 Measurements required by the Institute of Colour

Since this equipment does not exist in Córdoba, an approximate technical reading of light incidence was obtained by means of a luxometre, which measures the percentage of light reflected by different surfaces where daylight strikes. This percentage of the total incident energy is called reflectance and is related to one of the three variables of colour which is the value: the bigger the reflectance the lighter the perceived colour. However, this measurement does not allow discrimination between hue and saturation. The measurement venue was at Buenos Aires Street; the measurement type was with natural illumination levels and reflectance in vertical walls. The vertical iluminance measurement (EV lux) was made with a luxometre or iluminance metre: Gossen. Model: Panlux Electronic for Eng. Pablo Bobatto from the Centre of Acoustics and Illuminating Engineering (CIAL) of the National University of Córdoba, Argentina.

Table 1. Measurement of vertical iluminance on "Popeye" façade.

Measurement point	Direction	Measured value (lux)		
		Morning	Early afternoon	Afternoon
A2	South	22 000	4 000	700
A2	North	4 500	14 000	750

3.3 Measurement of reflectance in vertical surfaces

Three measurements were made, one of this was on "Popeye" façade:

Table 2. Measurement on an orange wall "Popeye" façade.

Measurement point R3	Measured value EV (lux)	Reflectance
On wall	34 000	0.224
Reflected at 30 cm	7 600	

3.4 Inherent colour – perceived colour verification - NCS - Y50R
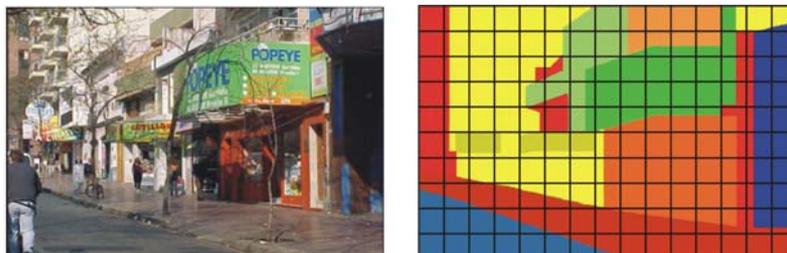
Month: August. Time: 10:30 AM.
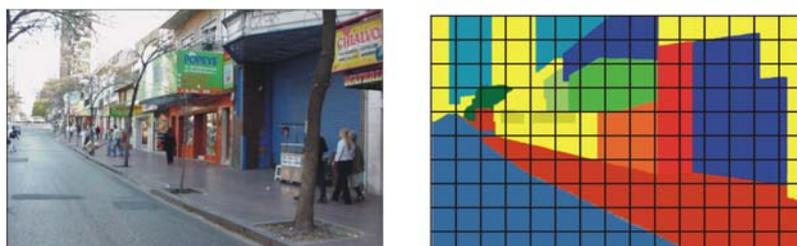
Month: August. Time: 5:30 PM.

Table 3. Comparative chart – Inherent colour – Perceived colour.

		Inherent colour	Perceived colour	Comparative samples NCS
10:30 AM	Image 1	Y50R	S0585-Y40R	S1080-Y40R
	Image 2		S2570-Y40R	
5:30 PM	Image 1		S1080-Y50R	S0585-Y50R
	Image 2		S2070-Y50R	

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Color and design of pre-Columbian ceramics today

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ABSTRACT

Pre-Columbian designs can be used today in very important collections all over the world. I made a recompilation of signs and symbols used long time ago, and we can use them today in interior design. We can repeat all the symbols, taking care of them, looking for real sources of information. Indians made them with a religious signification, or thinking about rain and sun, and to have more animals. I can show examples of real pre-Columbian designs, made now by ceramics companies, not handmade, but like handmade examples. They used colors made by new pigments; it looks like original natural colors and surfaces textures. Forms and colors can be respected if we know the real sources of information.

1. ANTECEDENTS

As a base of my study, I made the evaluation of the colors that were the most sold in the most important Argentinean ceramic companies. All of them sell their products to the United States of America and enlarge their color palettes in international exhibitions such as CERSAIE, in Bologna, Italy, CEVISAMA, in Valencia, Spain, and COVERINGS, in Orlando, USA.

For the last five years, the most used colors in ceramic tiles all over the world were neutrals, white, natural, and light beige. I believe that the permanence of the neutral colors has a reason.

2. NEUTRAL COLORS IN CERAMIC TILES

Neutral colors are closely related to everyday life, the ceramic instruments in the beginning of civilizations started using earth materials. People use these colors because they are part of the common history of every civilization. There is also a social reason, related to the fear of commitment in the use of colors inside the homes, mostly in products that are not changed frequently. Depending on the country, the floor or the walls are changed every five or ten years.

Nevertheless, ceramic companies prefer to reduce this time to sell more products. They wish that people change faster their house colors to be able to increase their sales.

3. PRE-COLUMBIAN DESIGN COLORS

Colors used by pre-Columbian artists in Argentina where earth colors, those that they could get more easily. They used red, yellow and gray earth to make objects. For decorations, they used red, black, and gray. They used natural mineral and vegetal pigments; those colors are the same that best sell products in ceramic companies today.

The pictures show the best-selling products in the last five years. There are five color categories.

4. COLOR CATEGORIES

White has been the best seller in Argentina for the last 20 years. Like a laboratory, its image represents clean houses (Figure 1).

Natural colors: The color of the natural textile fibers gives light to the rooms, produces calmness and enables combinations with every color. It is the most chosen neutral, the second in sales, and the first in many countries (Figure 2).
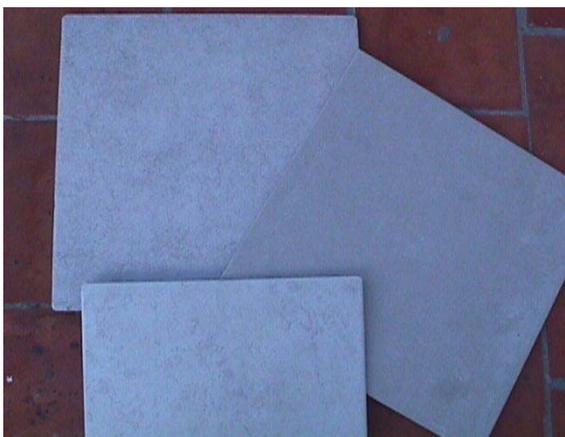
Figure 1.
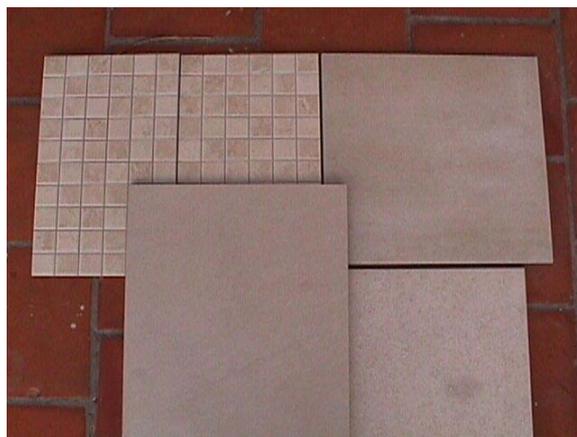
Figure 2.

Light beige: Sun reflects on this color, which is the most chosen for kitchens and rooms that are used everyday; it gives energy, combines with colors from natural pigments, and also with plants, near gardens (Figure 3).

Terracotta is the natural color from red clays; it is found in the northeast of Argentina. It is the typical floor of a country house. In Spain there is a great tradition in using this color. In Argentina, companies like Losa and Loimar make rectangular and square floors of different measures (Figure 4).

Figure 3.
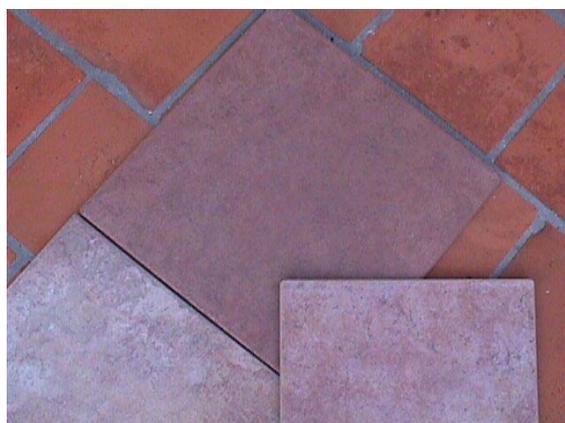
Figure 4.

Gray-green was used to decorate primitive vases. It appears in fifth place in buying preferences. As it is a dark color, it is used combined with lighter colors, and appears as an accent, not in all the room (Figure 5).
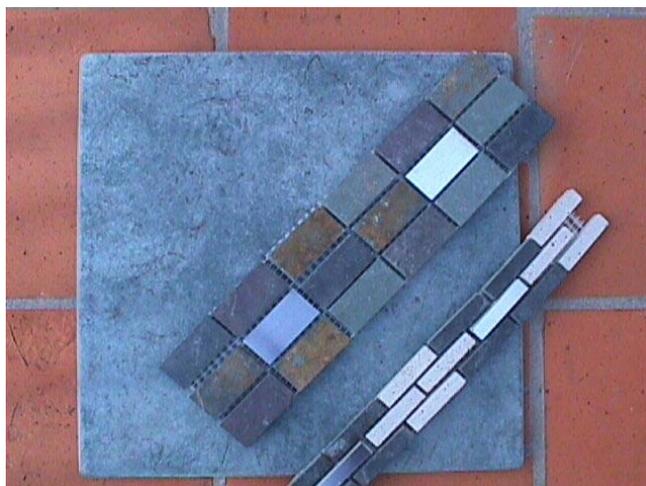
Figure 5.

5. BORDERS

We use white borders with red and gray accents, like in Purmamarca, Jujuy, Argentina. This triangle border shown in Figure 6 has these colors.

Natural is connived with natural, copper colors, and beiges. It is often the main color in the entire house. Sometimes without borders, geometrical figures are used as the only decoration in bathrooms and kitchens (Figure 7).

Figure 6.
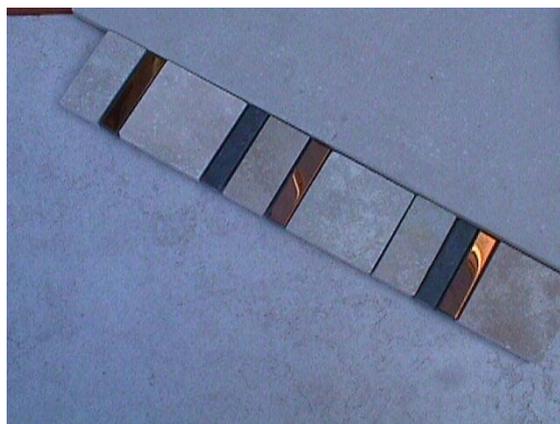
Figure 7.

Beige can be complemented with wood colors; we use also warm colors (Figure 8).

Terracotta invites us to use vivacious colors, like red, green, and yellow. In Figure 9 we can see a design recreating antique symbols.
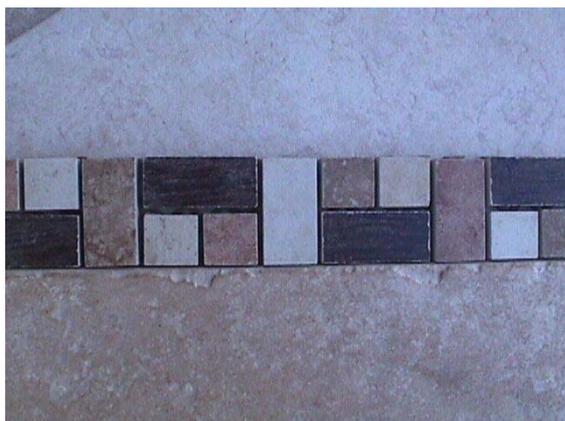
Figure 8.

Figure 9.

Natural is the preferred color combined with gray-green. It reminds us of ceremonial places with staircases, and also crosses which evoke symbols of life and water. They also represented the "four elements", with a cross: air, earth, fire, and water (Figure 10).

New developments, based on antique drawings and natural pigments would be good sold nearly, because people want to live near nature, and the same voice in their interior tells them that we are earth made, and those artists who made very nice and simple designs have the truth about the secret of life (Figure 11).
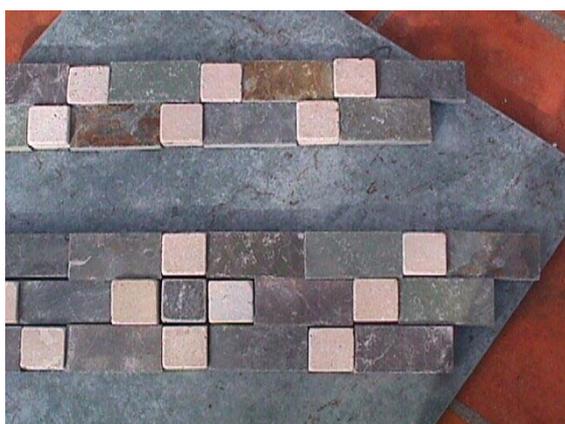
Figure 10.
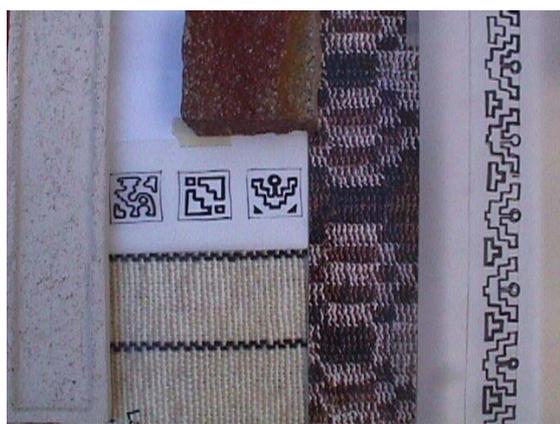
Figure 11.

ACKNOWLEDGMENTS

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Chromatic strategies: Decisions around artificial coloration of natural materials at product's design process

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ABSTRACT

When natural materials are chosen to work on the dilemma will fluctuate between keeping the natural colors of materials and changing them. This work explores the possible variations of natural-material's color and cesia through the application of artificial covers, arranging the variables of both spatial and spectral light distribution, in such a way that they work as a reference tool to make further decisions around the use of color in product's design processes.

1. NATURALLY ARTIFICIAL OR ARTIFICIALLY NATURAL?

Product design, as all human activities, is a *cultural process* that generates new objects as an answer to people's needs or desires, creating at the same time an *artificial environment* for men to live in. This process is based on a *central strategy* that leads the professional by organizing the variables of the project (morphology, production, communication, function, etc.) for the product to be the result of certain aim and fulfilling user's requirements.

In product's design, the materiality becomes one of the main defining characteristics because it sets the physical and technological possibilities, and through them, product's morphology as the result of form, texture, color and cesia[1] of the material chosen. This materiality may vary according to the functional or aesthetical needs of the project, but the choice will be fundamentally restricted to the use whether natural or artificial materials.

Artificial materials are those made by the combination of elements through chemical processes, transforming natural or synthetic elements in raw materials such as plastics, metals, ceramics, etc. In these transformation processes the chromatic properties of the materials will be defined by the elements included in the combination as well as by the proportion of the quantities used.

On the other hand, *natural materials* are those who could be found on nature and need only physical transformations to be used in production, such as wood, cane, stones and fibers (silk, cotton, rattan, etc.). In these cases the chromatic properties are naturally produced and only could be modified in different proportions by artificial methods.

The reasons to introduce color into materials are variable, but most commonly the purpose is to enhance the appearance and attractiveness of a product and improve its market appeal. Indeed it is often color what first attracts the attention to a particular object. Paints, coats and stains are the most common ways to artificially change the color of materials, and could be applied by several methods, according to the production scale and the aesthetic wanted, in almost every material. However, artificial coloration is used more frequently on natural materials, precisely because its color could not be modified before it is used in production.

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[1] Jannello (1984) sets this four variables as fundamental to define our visual world, introducing the term *cesia* to define spatial distribution of light. This concept was developed in Caivano (1991, 1996).

2. MAN MADE SURFACES

Of the many ways in which light can interact with objects, Caivano (1991) name three that enclose, from the physical point of view, any processes produced by light when reaching an object: absorption, permeability and diffusivity. These three could be arranged in complementary scales, measuring different aspects of the phenomena.

Absorption refers to the variation of the quantity of radiation reflected or transmitted by the surface, being on one end of the scale *darkness*, as total absorption, and on the other end *lightness*, as total re-emission.

Permeability measures the percentage of light that is seen to pass through the surface. This scale goes from *transparency*, when surface appears absolutely permeable, to *opacity*, when it is completely reflective.

Diffusivity defines different degrees of re-direction of light, having on one end *diffusivity*, with infinite re-directions, and on the other *regularity*, with only one direction of re-emission.

Then, it is possible to organize these three scales on a conceptual model, which could work as an operative tool in design processes, including all ranges of every variable, and also its multiples combinations.
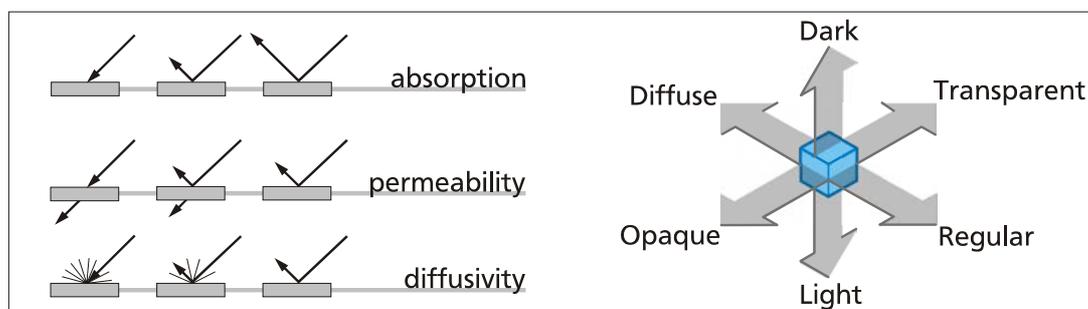
Figure 1. Variable scales.

But what happens when an artificial cover is applied on an object? Any kind of cover will modify, even slightly, the perception of a material, because it creates an additional surface over the original one. These changes occur whether by the way cover reflects, transmits or absorbs light, or by the modifications that the pigmentation causes on color and texture. In every case, all decisions should consider the available coloring possibilities from the technological, communicational and functional aspects of the project.

Artificial covers are commonly used to protect materials against external agents that could damage it. Nowadays, the technological development expands these possibilities, allowing the designer to decide product's aesthetic without loosing quality performances.

Coloring processes for different materials bases on attaching color elements to the surface, in a way that surfaces are totally or partially covered with paints, dyes or coats by means of several techniques, which depend on the material. Then, the color of material is modified by the effect of pigments and dyes due to the modification of the spectral distribution of re-directed radiation, but it is also changed by the variation of its spatial distribution, the cesia.

Beside the chromatic characteristic, paints, dyes and covers have what is commercially called *finish type*, that define how is going to behave light when it gets to the surfaces. Popular cover finishes are named with terms like matte, eggshell, pearl, satin, semi-gloss and gloss to accurately differentiate these effects, depending mostly on the vehicle characteristics.

With an opaque paint, the color of the material is hidden, because the finish layer blocks light, leaving on surface only the pigment color. On the contrary, translucent or transparent covers produce a mixture between the material's color and the dye's color, leaving the light

pass through, and acting like a sort of filter. With a translucent or mostly transparent finish the tone of the material itself becomes an important part in the final color result.

In terms of diffusivity, matte paints scatter light rather than reflect it regularly, creating flat, opaque color, and glossy paints reflect light mostly in a specular or regular way. In general, the higher the gloss the more intense or saturated the color.
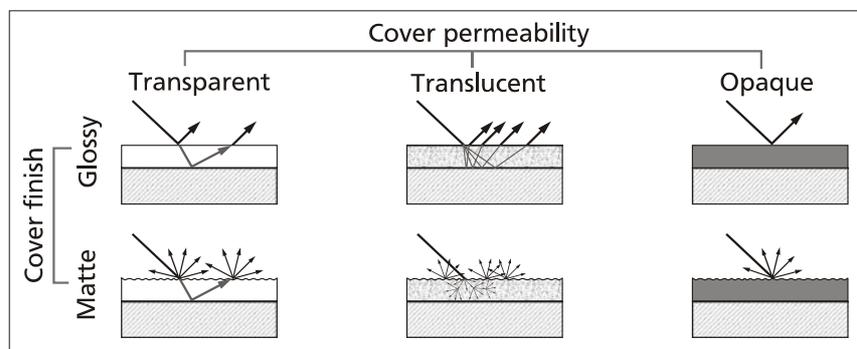
Figure 2. Cesia effects.

The final color is, then, the result of the modification of the incident radiation as a combination of both effects, one produced by the variation of the spectral distribution, and the other one by the change in the spatial distribution. Additional effects take place when the finish layer is permeable, because not only covering surface is reached by light but also fall on material surface beneath it, affecting also the perception of original texture. The tones and colors of all layers are combined and reflected to the observer's eyes as the finish color.

3. THE FINAL CHOICE

Natural materials could be recognized not only by its color, but especially by its texture, which could be either visual or tactile. These two aspects, allow people to *learn* a material through the construction of a symbolic whole, and to *recognize* it later by the sedimentation of this learning in memory. This mechanism makes possible, on one hand, *imitation*, through artificial reproduction of natural characteristics, and on the other hand, *re-signification*, through the, also artificial, transformation of the originally natural conditions of a material.

Color and texture, as signs of materiality, are visual variables that may represent either naturalness or artificiality, according to its relation with the original characteristics of material memorized before. In that way, these visual variables could be arranged in complementary scales that conceptually organize all possible combinations.

Therefore, artificial covers could be strategically used to create different sensations, when the surface of a natural material is covered with any kind of paint or dye.

Many products could be quoted to exemplify these intentions, but in this case it would be much easy to compare if products of the same category are chosen. Furniture design is one of the areas that use natural materials more frequently than others in product design. Then, here are just a few significant cases, among all other possible, to show how the use of artificial covers follows the central strategy.

Exalt: Gaudi's furniture (Figure 3a) expresses and exalts materials through the visual work on natural textures and the use of transparent varnish covers with extremely high levels of glossiness. This cover changes the tactile texture, making it completely different from natural wood. Then, he uses gloss as a tool to delimit form, and texture as a way to communicate that structural characteristics of material could be, also, elements with aesthetic value.

Abstract: De Stijl movement's intentions were to reduce sensations and impressions to the most basics aspects, rescuing the possibility of making individual interpretations. Rietveld's chromatic scheme (Figure 3b) responds to a desire to hide materiality through the use of a completely opaque cover. The color choice matches the aesthetical values of the movement, using particular colors as conceptual symbols.

Figure 3. Relations between color and texture in furniture design.

Proclaim: The Arts & Crafts movement tries to rescue craftsmanship values, following the functional and aesthetical rules of middle age guilds. In furniture design, Stickley (Figure 3c) used natural materials with hand finishes, keeping original color and texture, visual and tactile, to make a statement on the ethics values of production. The finishing is matte, alluding to a subtle and naturalistic aesthetics.

Diversify: Salix value-chain operation was developed to generate products with high added value based on inexpensive native materials (CEMA 2003). This way it could demonstrate the power of design as a competitive tool. In Estudio Blanco furniture (Figure 3d), the original texture is kept on sight, as a sign of material, but re-signifying through the modification of color.

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Light as a genetic element of the image

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"Constitución e Interpretación de la Imagen Artística" (Constitution and Interpretation of the
Artistic Image)

In this paper we will try to synthesize the cultural references and the basis of art languages within the 20th century. That will make evident the evolution of colour as main character in the work of art. This way, we intend to contrast modernity and posmodernity periods in the way colour studies are organized. We can find different arrangements on this matter.

Colour studies are relevant for structuralist theories that limit and put language in order. Thereby, compositions and art works in that period are defined just to overvalue structures (to imply space but without plainly talk about it, with the exception of some forms of sculpture and architecture) that best attend colour, form and texture.

Starting from these data, a deep change on image construction is shown, and therefore, also on the construction of plastic and visual languages. On that setting, colour is placed within a constant enrichment system, in which all elements feed each other and the links among genetic elements remain opened.

Conceptual art stresses the evidence of the inseparable link between ideas and materializations in artistic creation.

Minimal art lays the open image constitution system bare. This is capable of joining modernity dominating elements (compositive structure: colour-form-texture) with those elements that first originated them (space-time-light-matter).

Some artists' pieces of art accentuate the significant sense of physical as well as the perceptive and receptive experience. Those pieces *re-significate* the genetic elements showing, this way, the intimate indissoluble relationship between the dominant elements in modernity and those rediscovered to be main characters in artistic movements; that, in the other hand, will lead to posmodernity, as shown in the graphics attached.

Light is set to be the space and surfaces descriptor within natural world system of things. Also describes manipulated spaces and objects systems within artificial world. Light evidences matter bounds in every forms and possible variations. And is precisely its contact with matter that causes the receptor the sensation of colour when absorption-reflection phenomena occur.

Qualities on matter surfaces will be shown depending on a certain light incidence angle. In Modernity time, those qualities have been taken as texture. Texture has come to enrich the influence of this perceptive appreciation with colour appraisal, being both sensations different aspects of light-matter-space-time treatment as a world knowledge experience.

For artists' work, light turns from a passive element into an active and determinant one for the consecution of their pieces of art. Therefore, a new implementation in art languages studies is needed as a strategy to feature and evaluate pieces of artwork within this new point of start. At the same time, we have to say that most art academies pedagogical programs are immerse in a period in which colour sensations should be studied, never more in the margin of light and limited matter, but as a whole with the rest of genetic elements.

In this set the Research Group HUM-480 "Constitución e Interpretación de la Imagen Artística" has been working for a long time within the work of art perception research area.

We have paid special attention to the so-called *genetic elements of the artistic image:* light, matter, space and time, where colour remains as an important element in the artistic language.

At the beginning of March 2004, a theoretical-practical seminar was carried out with the Buenos Aires National Institute of Art professor Mauricio Rinaldi, which also works in the lighting area for the Colon Theatre of Buenos Aires, Argentina, and is a relevant member of the Argentine Colour Group. The seminar was called "Lighting in Art and Stage Design".

In this seminar, the light work was treated from a basically technical point of view (electric systems, power phase and distribution, external-internal knowledge about different spotlights and mixing-light desks, etc.) to a special focus on the significance, that is, not just on the *how* but on the *why* to use a certain lighting sketch. Aesthetics of light and communication theories were also analysed, to come up with the consideration of light as a communication element inside the object of art, as well as stage design or plastic arts.

The experience of working with 49 students was very interesting. They made very complex narrative pieces of artwork, in which light was considered part of the communicative exercise. The above-specified members of the research group have developed a communication about this experience. The importance of this research lies on the integration of the Light and Materials Laboratory[1] into the Faculty of Fine Arts of Granada University teaching practice.

Images of this experience show the sequence and changes of paradigm in visual languages configuration. The relationship of light and matter not only shows colour but other very complex and richness phenomena that take part in the construction of images. That is, the opacity and translucency contrasts, different reflection stages that will indicate significant aspects and introduce matter blendings in matter structure surfaces, etc.

The work of the Research Group HUM-480 studies this open systems of genetic elements that are articulated themselves within the appearance system. The relationship of light and matter as an actual specific space-time experience, in which they are configured within a geometry that evidences the complexity and richness of images construction. These images are not possible without a reception; in the same way colour sensation would not occur without a receptor that should eventually transmute the reflected radiation into colour sensation.

A new scope of development is happening in visual and plastic art:

Artists whose art works are in re-definition and making wide new strategies in art language.

Open interpretation systems in a hermeneutic key: materializations, referential and virtual images. Senses or real interpretations. Senses or referential interpretations. Slidings and transgressions, etc.

Redefinition of nature mute language into plastic and visual images language: interpretative projection. Constructive projection. Pedagogical projection.

From art, the relevance on these studies set the basis on visual languages, the narration by means of which we understand and create worlds.

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[1] The Light and Materials Laboratory is a creative and technical research project with the purpose of integration in the new syllabus of the Faculty of Fine Arts studies.
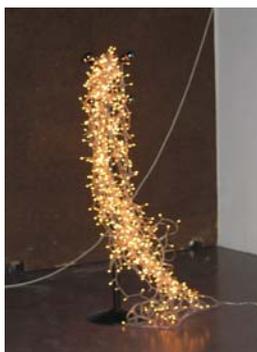
Next, we will show some artists' work that can exemplify all what has been exposed.

Björn Dahlen: *Club Superspace 3, Charm-Sphären (Deuterium Attezione)*, installation's view. Kunstverein in Hamburg, 2001. *Andrómeda*, wood, neon and mixed media, 1999. Artist, sculptor and stage designer born in 1974 in Munich, Dahlen works in Berlin. The installations retain the spirit of *arte povera* because of the austerity and simplicity of his work. Materials used: neon tubes, wood, video monitors. Soft techno lighting, romantic or multicolour, reflects intersideral space recalling the galactic myth by means of light.
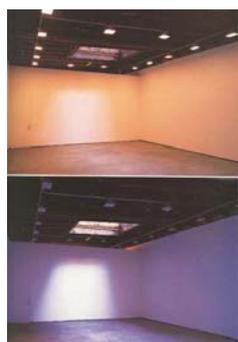
Martin Creed: *Work Nr. 227*, the light in a room going on and off, frequency every 5 seconds, variable material and dimension, 2000. This artist uses gallery room as container and measurement unity. Born in 1968 in England, he lives and works in Italy. He uses light as modelling element in the exhibition space. The room is empty and the normal illumination is substituted with intermittent lighting that blinks in five-second gaps. With this minimalist installation the artist catches the attention over physical space through the play of light.

Carsten Höller: *Light wall*, installation's view, Prada Foundation, Milan, 2000. This artist creates a successful combination of art and science. He tries to wide and spread the boundaries of human perception, searching psychological sensations. If we want to open our perceptive horizon, we should give up our habits and certainties. In this piece of art, 1920 bulbs emitted light and heat, switching on and off in a 7,8 Hz. frequency gasp. Even with their eyes shut, the spectators could not hide from light. Brain is compared to an electric system that synchronizes external impulses.

Jacques Herzog and Pierre De Meuron: *Goetz Collection,* Munich, 1992. This is an exhibition gallery. At a first glance it might recall the structural clarity and functionality of pieces by Mies van der Rohe, but a deeper analysis reveals a more complex and uncertain character. Distance between apparent and real is shown also in the building structure. The rhythmical division that the supporting vertical elements produce, call for diagrammatical clarity in rationalism. The upper and lower floor feature light in the way of a skylight.

Norman Foster & partners: *Centre of Industrial Promotion,* Duisburg, Germany, 1993. We can watch light and architecture joining in a perfect way. This new city council promotion central office intends to be emblematic of German region Ruhr new economical revitalisation. This building is sited in microelectronics Park, also by Foster, which is composed by a group of buildings set downtown. The Promotion Centre is glass coated over the concrete structure. This makes light to reflect outside as a screen. If watched at night, with its blinds open, this building glass outside wall has a minimalist interpretation. In daylight, the shinning closed blinds offer an appearance of a reflecting and opaque frontage. Foster's modernism exemplifies the use of light as the main character in architectural design.

Friedrich Förster and Sabine Weissinger: *The Magic House.* These artists have developed a technique in which big slide images are projected over huge surfaces. They have been developing this technique since the eighties and have come up with a computer based control system. This way images can be manipulated to fit the building structure and dimensions. One of the main characteristics of the Magic House project is that integration between building and aesthetic design projection is perfect. Building façade turns constantly into different conceptions according with the topic related, changing from dynamic moving images with sound to those slow track changing static ones. "Our main target is not just to illuminate buildings, but to enhance its architectonic, historical and aesthetical values, as well as the same place where they are set", says Förster. Building artistic lightening and projecting is a young gender within the art practices. Förster and Weissinger illuminated the inner spaces in Cologne St. Peter's gothic cathedral, accepting the challenge of lightening the second biggest gothic cathedral in the world. After the sunrise, the Magic House spectacle started when 6 huge projectors were switched on inside the cathedral. Projected light over walls, vaults, high altar and columns would show images of architectural composition taken from the same building: tessellated pavement, tracery and stained-glass windows... Images changed speed from a slow star rain to a quick flow of images turning colours and shapes. The spectator perceives a sudden sensation of sliding walls, rotating columns and that the whole church starts to move. Movements are soft, though, and invite the audience to enjoy the show and think over life, colour, movement... "We search for a 3D sensation with our projections so that we can provide the inner spaces with life", says Förster.

View of the interior of the Cologne cathedral, Germany.
Friedrich Förster and Sabine Weissinger: *The Magic House, LichtRaum Dom*. View for the Chorfestival 2004 in Germany.

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New materials for contemporary art: Experiences with hair dyes on supports of different nature

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ABSTRACT

This paper proposes an experimental pictorial technique that uses hair dyes —instead of the traditional pigments and agglutinatives— on cellulose, protein and synthetic supports. The experience has been done with seven kinds of hair dyes (permanent and no-permanent hair dyes) and a natural dye (like a contrast) on eleven types of supports.

1. INTRODUCTION

The out of context use of hair dyes with artistic purposes implies an innovation that opens a wide field of research. The application sometimes fails and on other occasions succeeds but either way they open a broad range of possibilities of artistic expression.

The need to adequate the technique to the support made us compare the results obtained on protean material (the ideal for this kind of dyes whose natural support is hair) with those obtained after using others types of supports (cellulose and synthetical supports in which the degree of color fixing was not so high. But, because of that we obtained a wide variety of tones what enlarged the expressive richness. The base color of the different support samples, contributed to enlarge the shades of the final works, and not disturbed the results of the different estimation indexes tables because it was took into account before their elaboration. In the same way, the different qualities of the used fibers enlarged the textural richness of the artistic pieces (Figure 1).

Figure 1. Painting I, 30 × 46 cm.

2. AIMS OF THE STUDY

The main aims of the study were:
- To test the color fading by studying the resistance to humidity and light of the different products used on each support, comparing the results obtained with synthetic hair dyes with the results obtained with a natural dye like the onion dye.
- To take into account the expressive possibilities of the techniques and the materials used. This aspect was made real by producing two paintings (Figure 2).

Figure 2. Painting II, 46 × 46 cm.

3. MATERIALS

3.1 Synthetic dyes

Lanocolor. 57. Copper. *HENRY-COLOMER* (Colouring cream).
5.0 Natur-Color. Natural highlights. *3.* Red hair. *HELENE CURTIS* (Colouring emulsion).
Majirel. 10 ½. Platina blond. *L'ORÉAL* (Colouring cream).
Preference. Imedia. Copper light golden blond. *L'ORÉAL* (Colouring cream).
Lanocolor. 57. Copper. *HENRY-COLOMER* (Colouring cream).

3.2 Natural dyes

Natural onion dye.

3.3 Bleaching agents

Super meches. Extreme (Bleaching powder).
Nirvel 40 V°. Oxidant cream for hair.
Acetic acid.

3.4 Supports

Cellulose supports: cotton, linen, jut.
Synthetical supports: viscose-polyester, fibrane-polyester.
Protein-based supports: felt, suede, leather, dog hair, sheep wool, human hair.

4. METHODOLOGY

The different experiences were systematized in a catalogue made out of cards of dye where the results obtained with the different hair dyes and supports were registered, following the methodology proposed by Kate Wells (1997) for the classification and preparation of patterns. In the same way, the numerical experimental data were classified in five tables of indexes of the estimation —resistance to the humidity (1-5), resistance to the light (1-8), indexes of satisfaction (referred to the artistic result) (1-5), indexes of difficulty (referred to the rate of difficulty in the capacity of fixing the color to the support) (1-5), indexes of adequacy (quotient between satisfaction and difficulty) (0-5)— according to the standardized methodology of industrial catalogues of stuff dyes samples.

5. CONCLUSIONS

The resistance to humidity of a dyed material is good if it is a protein material. If the material is cellulose-based the humidity resistance is average and with synthetic materials the humidity resistance is poor. Anyway fast dyes show a stronger resistance to humidity.

Natural dyes do not appear very appropriate to dye synthetic textiles but are less vulnerable to light than synthetic ones.

Dyed protein materials are less vulnerable to light than synthetic ones and dyed cellulose materials have an average resistance to light.

The effectivity of the dye application is low when synthetic materials are used and high when using protein-based materials.

Wool retains colour better than dog hair.

Wool, suede and felt are the three most appropriate materials for the tested dyes.

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Projection of green fluorescent light upon tulle and a female body: Practical experience

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ABSTRACT

The following work shows the results of a research carried out in the Faculty of Fine Arts of the University of Granada (Spain) in the year 2000, within the course of Painting Techniques corresponding to the final year of the university degree. The main objective that motivated this study was to empirically and theoretically investigate the idea that it was not only possible to paint "for sight", but it is also possible to paint for "hearing" and for "touch". The projection of a green fluorescent light upon tulle and a female body were the resources used to achieve this experience, which leaves a door open to reflect on the possibility of mixing lights, sound and textures using similar theoretical processes to the employed in the physical mixing of colours to produce a painting.

1. WHAT IS THE COLOUR OF CARESSES?

"What do kisses smell like? What is the colour of caresses?" These two sentences recently headed an advertisement on Spanish television. At first, they may seem absurd. However, if we study how our perceptions develop and how they are stored in our memory, they are not so absurd after all.

Imagine a ball that bounces past us. We see its colour, are aware of whether it is made of rough or soft material, we hear how it bounces, we notice where it lands and calculate how long it will take to bounce again. However, if we remember that instant, we probably will not remember only those characteristics. We will also remember the street we saw it on, whether the air smelled humid because it was winter, whether it was cold. We may even remember the taste of the sweet we were eating when we saw the ball. We will remember the perceptive processes that we were undergoing at that precise moment, processes in which most of our sense were probably involved. Therefore, it would not be too preposterous to talk of the "colour of caresses" or the "feeling or sound of a colour". This idea planted the seed from which our research for the course in Painting Techniques at the University of Granada, Spain (year 2000). We proposed to develop an installation in which light and colour would be appreciated not by sight alone, but also by touch and even be ear.

2. "PAINTING" AND FEELING ON STAGE

Polish artist Tadeusz Kantor's concept of scenic space was central to achieving our objective. In an interview published in *Los Cuadernos de Teatro* (Theatre Notebooks) the artist explained, "I do not wish to be known only as a man of the theatre because, actually, above all I am a painter. In addition to painting, I write and do theatre" (Vidal 1983).

If we think that "creative activity forms part of the environment of different languages for expression" (Bassols 2003: 14), it is logical that Tadeusz Kantor's conception of art should

arrive at the conclusion that there is no separation between the arts, no difference between theatre and painting. In his manifestos he speaks of "art", in general. Situations occur in Art that could be related to painting, music, literature, and so on. Or to all at the same time, without distinction.

When Kantor prepared a play, he was "painting" on stage. He took into account aspects that are normally associated with painting, such as composition, rhythm, intonation, and harmony. He played with all of these elements to tell the spectator about his memory's atmosphere. He uses his memories as a compass in his creative process, without narrating his past, but only recreating moods that could be understood by as many people as possible. He expresses them on stage by recurring to repetition, to reality broken down into objects, to the notion of death. He uses rooms (as in *Wielopole Wielopole*), dummies (as in *The dead class*), to armies or circus tents. His scenes are like "paintings" in which aspects are taken into account that are related to the theory of colour, composition, and spatial balance, for instance. They are pieces with which he seeks to wake the senses and enter into contact with memories and emotions in the spectator's minds. To that end, Kantor acts his (amateur) actors to follow the "semantic and rhythmic mass of the performance", ruled by the artist's memories, and to make them their own. He encouraged them to improvise, to let their emotions to flow with their sensations, to be themselves. Lecoq describes a similar procedure in *Le teâtre du geste*:

> If I imitate the sea, it is not a matter of drawing waves in space with my hands to make people understand that it is the sea. It is to seize the movements of the sea with my own body, to feel the most secret rhythms so the sea will live through me. Then I discover that those rhythms belong to me emotionally. Sensations, feelings and ideas appear that I, in the background, reproduce. I explore, starting with energy, making my movements more precise. I choose and transport my physical impressions. I create another sea, a sea that belongs to me and defines my style. I could have drawn it, created the word or the music. The word resounds in my body, one becomes the other in the images. (Lecoq 1987: 94)

After analysing Tadeusz Kantor's approach, our research propounded several objectives:
- To create a space in which to "paint" by projecting light on a body. Special emphasis would be placed on the elements that are normally used to analyse a painting: composition, rhythm, balance, colour, intonation, chiaroscuro, line, space, and perspective, for instance.
- To focus on the expressive qualities of the elements employed in the installation, particularly touch and hearing, as well as sight.
- To create a favourable atmosphere for the spectators to analyse the work in depth, making it possible for them to relate their perceptions with previous experiences and to feel emotionally involved in the installation.

3. PROJECTING LIGHT ON A BODY

To develop these aims, we decided to delimit a rectangular space with white walls. Our idea was to intervene on it from the inside with artificial light. Therefore, it was essential to recreate an environment without natural light.

We decided to work with green fluorescent light, given the expressive qualities associated with green. In addition to the light, we would have two more main figures in the installation: a female body and a dress made of tulle that would dress the body. The contrast between the

opaque density of the female body and the transparent softness of the dress would allow us to activate the spectators' sight, in first instance, and then their sense of touch.

Next, we decided to "paint" in our installation with the elements that were available. We carried out several trials and the final resolution was to place the model on a white pedestal, with the green light behind her, which greatly enhanced the chiaroscuro on our space. The result was a dreamlike image, at once strong and delicate, which some spectators even described as sublime. Clearly, the public found it evocative (Figure 1).

We paid attention to composition, playing with the masses so the image would be balanced. There were proposals to have the model move to the rhythms they composed, without losing sight of the importance of the work's verticality. Great care was taken in where the light was placed, and its effect on the white walls and the body, which as completely against the light, defined only by the model's silhouette. Attention was also paid to the where the public would stand to view the work, so their spatial perception would be tuned to the effects we sought.

The work was viewed in complete silence, which called the spectators' attention because they heard nothing but their own breathing and the model's breathing. The sense of sound was activated precisely by the lack of sound.

Figure 1. Projection of green fluorescent
light upon tulle and a female body.

4. CONCLUSIONS

Experiences such as this one make us feel that we can "paint" with more than just paint. We can paint with light, with different coloured cloths and materials, with the movement of bodies in space. We can paint to "touch" and to "hear" what was painted. We can paint to transmit sensations to the spectators' senses and have these expressions connect with their emotions. In short, we can "paint to feel".

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CULTURE, COMMUNICATION, EDUCATION

Light, colour, paints and pigments: A new concept in teaching colour for designers, architects and artists

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ABSTRACT

The SENAI/CETIQT Colour Institute in Rio de Janeiro, Brazil, integrates the colour-related activities of the different departments of the institution, particularly those of the Applied Colorimetry Laboratory, the Design Institute, the Faculty of Industrial Textile Engineering and the Faculty of Fashion Design. Based on fifteen years experience in teaching colour science for engineers, and colour fundamentals for designers, an ambitious new course is being now launched, aimed at professionals in every walk of life (designers, architects and artists among many others) working with colour. Making use of the specially constructed classrooms and the vast range of reference works, visual aids and demonstration material available, a team of a chemical engineer, two architects, two designers and two artists is preparing the highly interactive, experiment-based course material for the 376 hours post-graduate course to be offered for the first time in March 2005.

1. INTRODUCTION

Some years ago students of our textile design and fashion design courses were complaining about the lack of formal colour education in their curricula, and it fell to my lot to give a subject which we called *Fundamentals of Colour*. As it was fairly well received we thought it would be interesting to offer it also on its own, for a wider audience, and we organised a workshop called *Colour for Designers*. In both cases the students appreciated our efforts, and evaluated the course material as "interesting" and "useful" even "relevant" but all of them complained about too much being taught in too little time, and yet, they would have wanted to hear more about most of the subjects (Hirschler and Gay 2002).

Listening to our students and also making an informal survey among designers, architects and artists, the idea of a much more extensive, formal colour course began to form itself. It has been extremely encouraging to enjoy the full support of the directors and the Board of SENAI/CETIQT, all the more valuable in these times when, according to Willard (1998), "indications suggest an appalling lack of regard for color in contemporary art education."

A special classroom was constructed complete with three types of illumination (representing standard daylight, fluorescent "point of sale" light and incandescent light), a high-quality multimedia PC and video projector, 4 slide projectors and an overhead projector, and modular tables to make individual work as well group-work in pairs or in fours possible. A sink was also installed to facilitate working with inks and paints. This installation was considered to be the minimum to enable the teachers giving "lectures" and demonstrations and the students making exercises in the same environment, thus making seamless changes from one module to another. As SENAI/CETIQT already had a fully equipped computer graphics classroom, workshops with handlooms and screen printing tables and an extensive collection of books, colour order systems, demonstration material and other teaching aids, the

stage was set for the development of a new, fully-fledged post-graduate course called *Light and Colour in Design, Architecture and the Arts.*

2. SOURCES OF COLOUR EDUCATION

MacAdam (1970) traced the *Sources of color science* back to Plato and Aristotle, but it was only Goethe, at the beginning of the 19th century, who started in earnest the *didactic* treatment of colour.[1] His *Farbenlehre* was first translated as the *Doctrine of colours* and later as the *Theory of colours*, but even the most complete English translation (Matthaei 1971) contains only the "didactic part" in full, and only parts of the rest. Goethe himself said:

> A dread of, nay, a decided aversion for all theoretical views respecting colour and everything belonging to it, has been hitherto found to exist among painters; a prejudice for which, after all, they were not to be blamed; for what has been hitherto called theory was groundless, vacillating, and akin to empiricism. (Goethe 1810 [2000: 344-345])

Even if his hopes that "our labours may tend to diminish this prejudice, and stimulate the artist practically to prove and embody the principles that have been explained" didn't come fully true, it's undeniable that he started a new kind of thinking about colours. His influence is felt even today, but, in the controversies evaluating his contribution to colour science as either extremely positive or extremely negative, unfortunately only very few take the objective view that Ostwald did. Wilhelm Ostwald, the 1909 Nobel laureate in chemistry and himself an influential colour scientist acknowledged that Goethe "rightly challenged the previous conception of the physicist . . . that colour theory belonged to physics, and emphasised the part played by chemistry, and, in particular, by physiology" but also criticised him, because

> Goethe not only undertook the working out of a new physiologico-psychological domain, where he acquitted himself brilliantly, but also the replacement of the physical colour doctrine, which he looked upon as inadequate . . . Here he failed, because not only the knowledge but also the ability were in his case lacking for such an enterprise. (Ostwald 1931: 15)

While the course material will, naturally, deal with the history of colour education from the beginnings, its principal sources are the great educators of the 20th century: the masters of the Bauhaus (Kandinsky, Klee, Itten and Albers), Faber Birren (1965), John Gage (1999, 2000) and some excellent recent textbooks, such as those of Feisner (2001), Holtzschue (2002), Leland (1998), Long and Luke (2001), and Zelanski and Fisher (1999). Some of the exercises will be developed and/or adapted for our conditions using the original edition of the *Interaction of color* (Albers 1963), the seven contrasts of Itten (1973) and the student/educational sets available for the Munsell system (Long and Luke 2001) and for the NCS (Scandinavian Colour Institute 2004).

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[1] Of course we cannot disregard the work of Leonardo, Descartes, Boyle and Newton, but they are considered artists-scientist rather than educators.

3. PHILOSOPHY OF THE COURSE

3.1 Learning and not teaching

The traditional (Western) approach to teaching is nowadays much criticised, as Radloff and Sampson (1988) commented:

> The typical view of the tertiary teacher has been that of didactic lecturer. The traditional mode of instruction has been that of the one person talking and many listening. Many students perceive their role as passive listeners and recorders of the lecture content . . . they write much and understand little.

From the very beginning we have wanted our new course to be a *learning experience* for the students. Listening to the teacher standing in front of a blackboard, flipchart or, in the best case, the multimedia screen can be interesting for a few minutes, endurable for 10 or 15 minutes, but becomes unbearable beyond that. The importance of our "visual classroom" lies in the possibility to interrupt the *talking* as often as it is necessary and insert a *demonstration* or an *exercise*, deepening and intensifying the message.

The presentations themselves must be highly visual; none of the teachers will be permitted to throw lines and lines of text on the screen to be then read aloud (in the worst tradition of the representatives of the old school projecting barely legible copies of overhead transparencies copied from the textbook).

The exercises will be the "hands on" type using coloured papers and filters, and also pencils, watercolours and pigments rather than using computer graphics (which will be included in the course as a separate subject). Although computer simulations are becoming more and more popular in teaching colour (see e.g. Rogers 2000, Schanda 2002) we decided to use *coloured materials* instead, for didactic reasons. Computer graphics has reached such a high level that *virtually* everything is possible on the monitor and it is hard to tell what is a real optical effect and what is just a trick. In the extremely complex world of the interaction of colours: simultaneous and successive contrast, spreading and crispening seeing is NOT believing! The students must create the effects *manually* to fully accept it *visually*.

3.2 How much physics is too much for a designer?

Colour, by its very nature, is an interdisciplinary subject and has been treated so for centuries. The way impressionist and post-impressionist painters experimented with and found new ways in the treatment of colour owes a lot to a French chemist, Chevreul (1839), and to one of the leading American physicists of his day, Rood (1879). The visual basis of the CIELAB uniform colour space, used all over the world in the interpretation of colorimetric results is the Munsell system, designed by an American artist a century ago.

And yet, we find "xenophobia" between physical scientists/engineers and artists/designers (Green-Armytage 1999). Itten's *The art of color* (1973), one of the best known and most widely used books on the subject, a beautifully produced 155 page masterpiece, dedicates but one single page to colour physics. At its worst this animosity got so bad (in 1919) that a group of artists and art-historians led by the Stuttgart painter and teacher Adolf Hoelzel "petitioned all the German ministries of education to prohibit the use of Ostwald's system[2] and it was indeed banned in Prussia" (Gage 1999).

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[2] Ostwald himself tried to discover the laws of colour harmony based on psychophysical principles.

There is, fortunately, a growing number of colour educators who try to build "a bridge between art and science" (Green-Armytage 1981). Gerritsen's *Theory and practice of color* (1975) explains colour physics in a simple enough way not to frighten artists and designers away and Patricia Lambert's *Color and fiber* (1986) is a superb example of colour science applied in textile design.

We have decided to dedicate 16 hours of class to colour physics (out of the 72 hours of Fundamentals), mainly to the explanation of primary colours and colour mixing (additive, subtractive and partitive) using demonstrations with coloured lights, filters, papers and a diffraction grating and exercises using filters, pencils and pigments.

3.3 Which colour order system?

As musicians have to practice the scales so that they be able later to play or compose masterpieces, artists, designers and architect need to be familiar with "colour scales" or colour order systems before they can apply the colours following their inspiration. According to Judd (1960: 11) "When someone chooses a color system and engages in the long and difficult task of preparing the scales generated by it, the system becomes part of his own mental equipment". The fundamental question at the outset was to decide which colour order system we should teach in our course?

The two most popular ones are undoubtedly Munsell and NCS, but there is also the OSA system with interesting characteristics and the Ostwald system, important for historic reasons. An important consideration was the availability of relatively inexpensive student/educational sets for the Munsell system (Long and Luke 2001) and the NCS (Scandinavian Colour Institute 2004). Based on our positive experiences with both the Munsell (hue-value-chroma) and the NCS (hue-blackness-chromaticness) systems we are going to teach both: let each student decide which of the two is more adequate for his/her particular application. In our previous courses we found no difficulty in working with both, in fact one of the exercises of the NCS student kits leads "naturally" to the concepts of value and chroma.

Both the Munsell and the NCS are *colour order systems* in the sense that they are based on clearly defined principles, and this makes —among other characteristics— *interpolation* between the chips actually existing in the *atlases* or *collections* representing them. This is not necessarily the case with other colour collections (the best example being the Pantone) where the underlying principle is not clearly defined, and thus the notation of each colour is tied to the physical samples in the collection.

4. COURSE STRUCTURE AND CONTENTS

The course material is being developed by a team: a chemical engineer, two architects, two designers and two artists and the course will be conducted also in a joint effort. Each of the modules will be given 2 or 3 team members: theory and demonstrations interlaced with exercises will ensure the right dynamics of the course.

The course consists of three modules with a total of 376 hours + 2 months for writing the final paper and it will be offered in 12 hours/week.

Module 1

Fundamentals (72 hours)
- Physics and psychophysics: primary colours and colour mixing (additive, subtractive and partitive) exercises with colour filters and paints and explained by spectral demonstrations; the meaning of spectral curves, the effect of illumination;
- The interaction of colours: exercises based on Albers (1963) and Itten (1973);
- The philosophy and symbolism of colour, colour and culture (Gage 1999, 2000).

Colour order systems (48 hours)
- Overview of colour order systems;
- Munsell, Ostwald, OSA, NCS;
- Exercises with Munsell and NCS student sets; colour harmony based on colour order;
- Colour collections (Pantone, ScotDIC).

Module 2

Applications of colour
- Colour in industrial design (32 hours);
- Colour in textile design (24 hours);
- Colour in architecture (32 hours).

Colour in computer graphics (48 hours)
- The meaning of and how to work with HSB, RGB, Lab and CMYK;
- Colour management.

Module 3

Colour in the arts (48 hours)

Light and colour (48 hours)
- Lighting design;
- Illumination and colour: colour order and colour harmony exercises under different illuminations.

Methodology of preparing the final paper (24 hours)

Final paper (2 months)

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Colour, painting and computing

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ABSTRACT

Exploring digital colour and analogue colour through the physical and perceptual experience of making paintings. In my recent work I use *Chromafile*, a software program that simulates paint colour on the computer monitor in the creation of combined painted and digitally printed pictures. Chromafile relates virtual to material colour to set new pictorial problems by sharing a pictorial language through a common colour palette. My aim is to create paintings using original and specific research; the practical solutions and experimental data could have broad relevance wherever there is an established or potential use of digital printing, or where varied printed substrates are part of the output.

1. INTRODUCTION

For the past year I have had an Arts and Humanities Research Board Grant to examine the relationship between analogue and digital colour using new colour software, digital printing and hand painting within the same picture. This is a project that introduces colour and computer research into my studio practice to formulate new paintings and extend my pictorial practice.

2. COLOUR AND COMPUTING

Colour and computing was a shared project with Dr. Ferdy Carabott. We investigated the possibility of using the computer to explore colour ideas for pigment dyeing, printing and hand painting, processes that I use in my own work or when teaching textile design students. Understanding material colour (paints, dyes) and virtual colour became our key research problem with a view to making a practical contribution to the fine arts and textile research and practice (Lewis 1996, Carabott and Lewis 2001, Carabott, Lewis and Piehl 2002).

The difference between material and virtual colour was an unforeseen obstacle to our initial enterprise, we found predicting paint colour mixtures on the computer was impossible.[1] Extensive research led to an understanding of the difference between analogue and digital colour and importantly a method for reconfiguring the computer colour system (additive), to simulate pigment mixing (subtractive). The result of our efforts was a new colour palette: *Chromafile,* that works in Photoshop and other imaging systems.

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[1] Dr. Ferdy Carabott is a photographer and computer imager, I had no previous computer experience.

3. A METHOD FOR SIMULATING PAINT COLOURS
ON THE COMPUTER MONITOR

When yellow and blue are combined as pigments their mid-colour is a green, on the computer monitor the mid-colour between yellow and blue is grey. An important insight was to relate straight-line gradients between colours in Photoshop, to stepped, mixtures between pigment colours. We mixed colour scales between eleven hues plus black and white and using Spectrophotometer readings were able to plot their LAB positions, LAB is the conventional colour space for Photoshop. The paint colour pathways were curves, each one distinct to the particular set of parent colours. We were able to relate the paint colour pathways to the straight line gradients for the same sets of colours. The straight line gradient was then reconfigured to match the corresponding paint colour gradient. Taking a middle slice through LAB space produces an approximate colour circle, in this, the straight line gradient from yellow to blue can be compared to the paint mixture gradient which curves into green territory. In essence we bent the straight line gradient in Photoshop to follow the paint mixture with respect to hue and value.

A characteristic of paint is that a mixture between complimentary or opposing colours (red-green, orange-blue, yellow-violet, etc.) produces a mid-colour that is darker than the two parent colours; for computer gradients there is no deviation. Mixing black or white with various hues produces a change of colour as well as the intended value change, these factors were built into our paint colour gradient profile. Eventually we created sixteen step gradients for the eleven hues and black and white, a total palette of over 1000 colours, plus a gradient tool that could generate new colour mixtures. While the gradient tool uses conventional RGB straight gradients it is possible to produce colours that are close to the paint mixture by following paint mixing practices. Straight line gradients can be navigated by stages through LAB colour space to follow the curved pathway of the paint mixtures.[2]

4. A VIRTUAL COLOUR COURSE

Working with the ITRDU Unit at the University of the Arts, London I have used the Chromafile palette as the basis of a virtual version of the studio colour course I teach, the paint colour palette is used to access a body of knowledge and experience derived from Chevreul, Itten, Albers and Aach.[3] The Virtual Colour Course has progressed the Chromafile project and has been of practical help in supplementing the experience of students in my greatly expanded studio classes. Both software programs: Chromafile and the Virtual Colour Course have been used with my recent painting project.

5. COLOUR AND PAINTING

My paintings, which are essentially abstract and focused on colour relationships, had developed to the stage in 2001, that I began painting on left-over backing cloths from textile print tables.[4] Backing cloths are coloured with random fragments of images and patterns that are the residue of several, separate, unrelated printing sessions. For the finished picture the backing cloth serves as the physical support and perceptual context for hand painting.

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[2] This procedure is illustrated in a file: About Chromafile from www.chromafile.com.
[3] I worked as Herb Aach's colour research assistant at Queens College, CUNY, 1970-1971, he was a painter and the American translator of Goethe's *Colour theory*, Van Nostrand Reinhold, 1971.
[4] I teach on the BA Textile Design Course at Central St. Martins and the backing cloths came from the Print Workshop.

For my new work I have replaced the backing cloths with digitally printed, unprimed canvases of my own computer designed compositions.[5] From the outset my aim was to use the Chromafile palette to create digital prints that explicitly reflected and expressed my painting process. I began with mixed media compositions using found materials, photographs, fabrics and hand painting that I scanned and imported into Photoshop. Certain limited physical changes are made using computer tools but my main focus is applying Chromafile colours to the hand painted areas. Using a scale of greys to distinguish and separate the hand painted shapes, I am able to apply colour in a direct and automatic way, better able to relate each new colour and colour decision to the whole composition. The combination of hand painted marks and Chromafile colour produces my version of *direct* painting: colours are placed side by side, edge to edge to build the picture rather than used to glaze or overlay colours onto pre-existing images.

6. COMPUTING AND PAINTING

When designing the digital canvases I use a few easy-to-use Photoshop tools that either correspond to painting as with the paint colour palette, or offer new approaches to established pictorial problems.

The most basic tool is *Paint Bucket* with which I apply colours, sampled from the swatch pallet or from the *Gradient Mixer*, to different grey shapes and marks. Varying the *Tolerance* option with the *Paint Bucket* means the colours either fill a shape or over-run boundaries where the Value differences between shapes are closer than the *Tolerance* percentage recognises. The total composition can change radically depending on the tolerance of the colour fill; it offers control and "accidents" as colours can flood shapes and find unforeseen contours. This corresponds to significant oppositions in my own painting, practice where colours can be applied with a brush, as a monoprint or poured.

With the *Transform* and *Distort* option I can reframe a composition, by changing a vertical frame to a horizontal or square, or by combining different compositions into a single frame. A series of paintings where a single composition can be presented in different formats and dimensions is a new possibility despite the idea being so explicit in modern painting. The *Rubber Stamp* tool is used to remove edges after I have *Cut* and *Pasted* different compositions together; the tool samples part of the composition and repeats it as an area or brushed mark that will over-ride the original image. Parts of a composition can be relocated and rearranged as visually integrated marks or shapes. The painting parallels are obvious; however these effects that are very simple for the computer but are perceptually dramatic and significant in a painting, anything that can apply colour becomes a painting tool.

7. PAINTING AND DIGITAL PRINTING

When I begin work in the studio the painting is already well advanced, however the digital design is not a prescription for subsequent actions. Hand painted marks are applied as figures against the digitally printed (back)ground, which in turn contains images, shapes and colours that also create complex figure-ground relationships. Paint is applied to isolated, primed shapes or in certain works, as monoprinting directly across the printed fabric. The painted areas are masked off as squares, circles or ellipses, then submitted to a process that emphasises the tactile, liquid and material character of the paint. With only tentative hand painted studies and my previous work as an overall guide, initial studio results are mixed, so

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[5] The canvases were printed at the Textile Futures Workshop, London College of Fashion on a Mimaki tx 1600 printer to a max. width of 48 inches.

fresh thinking, new ideas and strategies are needed at each stage. The completed works combine painted and printed colour, the processes are distinct but they connect visually, the Chromafile colours can appear closer to the paint than to the scanned images and forms.

8. A NEW PICTORIAL SPACE

The introduction of the computer has made dramatic changes to my customary studio practice and to the look, meaning and scope of the paintings. At this relatively early stage of the project the potential for a combined working process has been clearly established but the areas for action and the different pictorial problems have not yet produced a clear or consistent line of development or a definable aesthetic character to the work. My "art" approach broadly is characterised by experiment, trial and reflection until new forms and satisfying relationships emerge. This process provides "research data" in the form of pictorial and material experiments, including mistakes and accidents that could have relevance beyond painting. This interests me as an artist, teacher and researcher; previous to this project my only use of computers was restricted to designing visual experiments, diagrams and colour samples to support the colour research for the Chromafile and the Virtual Colour Course.

Digital printing is exact and achieved quickly; change, experiment and improvisation are possible when preparing the computer artwork or by subsequent hand painting, direct printing or fabric manipulation. The potential is evident: the strength and intensity of digital colour matches the power, even character of paint, while the connecting and opposing of techniques and images produces an ambiguity and continuity to pictorial space. Definitive aesthetic solutions are yet to be achieved and judged, but what I have instigated at this time is a dynamic form of painting that significantly extends my visual expression.

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Teaching color plans

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ABSTRACT

"Color and Paint" the title of this year's AIC meeting covers a transversal area, which embraces philosophy, research and plans. Our contribution to the meeting will be to present the planning, development and results of the first Italian "Fashion Color Consultant" professional course, finished at June 2004.

1. THE FIRST COURSE IN ITALY FOR FASHION COLOR CONSULTANTS

The subject of our paper is the creation of a professional course in color, which was the first of its kind in our country. In fact in Italy the subject of color is taught at the academies of fine art, in visual arts colleges and in certain university faculties but only as one of the subjects of study included in degree courses of various kinds. In spite of the fact that there are numerous professionals (including the authors of this text) who exercise the profession of fashion color consultants, there had never previously been a specific specialization with a legally recognized diploma.

This year however for the first time the European Union has given legal recognition to a training program put forward by ourselves, which awards the professional qualification of fashion color consultant to the students who have attended the course organized by us. This is a highly specialized annual course, alternating 680 contact hours of lectures with 320 hours of work experience in companies of excellence, and has produced specialist color designers for the fashion sector.

Today we can say that thanks to this course the figure of the fashion color consultant has been specifically recognized both at institutional level and with the general public. In fact at the end of the course the ADI (the most important Italian association of design, which this year celebrates the fiftieth anniversary of the "Golden Compass", an annual award for the best Italian and foreign design projects) actually gave its support and expressed its approval for the new profession, presenting it to the city and to the press with a evening event.

For this first Color Consultant course we turned to the fashion business —where the term "fashion" extends to other fields of design too— because we have been operating in this sector for years, liaising with businesses and know where there is a need for specific color training. Fashion companies, *maisons*, ateliers, catwalks, show rooms, fairs and luxury shop windows make Milan —the city in which we live— an established capital of fashion and excellence, an attraction for buyers who converge there from all over the world. In this context with all their preparation and their operational capabilities fashion color consultants are versatile figures able to play a positive role in all areas of the business: corporate trend books, the color trends of the season, packaging and exhibiting.

It is also well known that the fashion industry, perhaps more than other business sectors, creates new colors every season in the form of color trend books, color books and color ways as well as cyclical musts. In fashion, color is the prime factor guiding consumer choice, the first visual element perceived and in this age of Internet and e-commerce, a highly significant

means of seduction and persuasion. In this perspective the market now needs professionals who are not merely self-taught or intuitive but who have a solid preparation and are connoisseurs of the aesthetic, communicative, emotional, productive and operational aspects of color, professionals such as fashion color consultants, the professional figure that we have put forward.

However, today one can observe how color tends more and more to be decoupled from seasonal impulses and to assert itself as a consequence of a social and cultural atmosphere, as the expression of the diversity of identities or of the plurality of the linguistic messages of a complex society. If Prada chooses opaque colors, dissonant and murky, Cavalli goes for exuberant tones, sun-drenched and optimistic, Versace for in-your-face ranges, turgid and baroque, while Armani, the king of *greje* (the term invented by him which is a contraction of the Italian words *grigio*, gray, and "beige"), never abandons his glazed and reflective gradations. Each designer, each *maison*, while constantly renewing its ranges, keeps to its "historic" colors which make it immediately recognizable to the general public.

We could say that "color is an emotion that is externalized, a dream that becomes an expression, an intuition that takes shape, a thought that turns into action" (Luzzatto and Pompas 2004).

We have had to deal with numerous problems of methodology and content. What kind of design abilities does fashion require? What kind of cultural background do you need to have? And above all how can one teach a logical and consistent procedure within the sphere of a project of aesthetic and sensorial emotion, which is by definition individual?

The first conclusion that we reached was that the color project —apart from the basic understanding of its perception, of its systemic representation and of the necessary operational instruments— requires the sum of different areas of knowledge, linked in an interdisciplinary vision. And if the aesthetic project is defined as a process of constant research and ongoing experimentation, its validity is entrusted to a capacity for interconnecting with the culture and the problems of the society of which it is the expression; thus the color project must be sensitive to the continuous changes of meaning, relationships and styles that post-modern life displays.

The chain of correspondence and meanings that forms the wealth of expression of color can be read in various keys, giving rise to an interpretation process that is continually redefining itself and updating itself with the passage of time. For example the events of chemistry and electronics are channeling perceptional and applicational potential into new categories and new possibilities, complicating the traditional teaching of color. For this reason this course has imparted knowledge which is at the same time both specific and interdisciplinary, spanning both the sciences and the arts on which the course design is based.

The course curriculum included some compulsory subjects, such as: basic computer science and skills, Adobe PhotoShop and Freehand, English and business administration. The remaining 400 hours, devoted to color, were subdivided into 5 modules:

- I *Basic Elements of Chromatics*: involving the study of the physical, perceptual, productive and systemic aspects of colors;
- II *Communication*: analyzing the potential of colors in terms of their value in signaling, conveying information and symbolism;
- III *Fashion*: the core syllabus most oriented towards the profession, which designed the historic palettes, color books, trend books and color ways;
- IV *Design*: which completed the preparation of the project with the work of the color consultant for interior design, drawing the attention of students to broader issues regarding color products and the spaces which contain them;
- V *Exhibiting*: which deals with color as an element for sequencing and narrating an exhibition.

2. MODULE I: BASIC ELEMENTS OF CHROMATICS

This module provided the basic notions of physics, physiology and perception with contact lectures and practical sessions based on "the infinite possible combinations of the three coordinates of color" (Luzzatto and Pompas 2004). For color addition synthesis the students visited the Laboratorio Luce e Colore (Light and Color Laboratory), of the Milan Museum of Science and Technology, for subtraction synthesis and color printing in four and six colors they were the guests of Fontegrafica, the most prestigious printing house in Italy, in Cinisello Balsamo (Milan).

The full range of colors for fine art —oils, tempera, acrylics, water colors— were illustrated by the most important Italian company that distributes painting products: it involved the choice of raw materials, production and the technical characteristics of the products, how to get the best use out of them in terms of efficiency and design application (Salvestrini 2003).

Some lectures were on synthetic and natural colorants for textile dyeing and printing, with a view to making the students aware of the problems of production and consumption compatible with the environment. "In fact today we are returning to an appreciation of the preserving properties of natural colors (keeping away mould, vegetation and moths) and of their therapeutic qualities (against bacteria, microbes and viruses), but also of their added value in terms of aesthetic quality" (Luzzatto and Pompas 2003).

The students experimented with natural dyes, dyeing samples of non-treated wool and silk in the laboratory, with madder (*Rubia tinctoria*), weld (*Reseda luteola*), cochineal (*Dactylopius coccus cacti*) and woad (*Isatis tinctoria*). The head of the Association "Couleur Garance" from Lauris (France) talked about the current status of the market in relation to natural dyes.

Three different color systems were then illustrated and the students, did practical work on these: the Munsell, the NCS and the Pantone systems, the last of which is used quite a lot in Italy in fashion design, even though many textile companies prefer to adopt their own dye-print book, with their own samples and color recipes, a choice that allows them in certain cases to insert charts showing sales figures and levels of customer satisfaction for the different colors.

From a knowledge of the color models and how they operate we moved on to the emotional and perceptional interaction that is established between color and surface, experimenting with the relationships between the materials, the finish and the surface as it is perceived and experienced. This is because color is the "expression of the accord between the energy being radiated, the substance that receives it, the eye that selects it, the psyche that understands it, the body that absorbs it and the subjectivity that translates it into emotion" (Luzzatto and Pompas 1999).

Particular attention in planning was devoted to the interference of the light-created atmosphere, both natural light modified by architectural factors and artificial light able to filter and modify the emission of color, in relation to the kind of support used. The lessons on lighting design, as part of the exhibiting module, completed this area.

3. MODULE II: COMMUNICATION

Today anything to do with the market —from communication, to the product, distribution, and sales— is based on the integration of the technical aspect with the emotional one, of

which color represents the most immediate visual interface. The attention of students was drawn to the fact that in an extremely competitive global market it is the so-called "symbolic economies" that determine consumer choice and with its expressive and symbolic qualities color fully belongs to these.

> Color, in the philosophy of an advertising campaign, works at various levels: perception, information and communication […] in the ongoing dynamic relationship between the fact that, on the one hand, the market is becoming more and more a mass market and, on the other hand, the need for buyers to assert their own individuality. Color is one way of offering consumers the chance to choose their own individual color and to identify with one of those on offer, thus personalizing their choice. It constitutes added value in terms of being fashionable and up to the minute and, in the multiplication and differentiation of ranges of colors, suggests exclusiveness in a context of mass production. (Luzzatto and Pompas 1992)

In fact it can be measured in the variety of sensory experiences and in the dimension of feelings in communication; it is one of the values which enables a brand to become imprinted in the memory and to be singled out among others, and which makes a product respond to the dreams and social needs of the consumer.

We have seen how advertising organizes color in terms of what it looks like, in terms of intuition and synaesthesia, which are rooted in the biological and cultural experience of society. Practical work in the laboratory produced the research project "Communication and Color", aimed at identifying in percentage terms the colors most used in press advertising of perfumes and beauty products for women. Particular attention was given to the name of the colors since the name itself is evocative and, together with the shades used, manages to sum up the characteristics of a particular article and its objectives in terms of communication. The students were able to see that in an advertising image the appearance and name of the color represent the essence of the product and the brand identity, acting with very strong persuasiveness, which —as Ernest Junger wrote— is a secret sensation, an inner acceptance that is independent of the will (Luzzatto and Pompas 2004).

The course aimed to consider and treat color as a "project within a project", an element which is fundamental, because it is the most accessible to the senses and it has the ability to transmit suggestions.

The module was completed with the study of a coordinated corporate image, packaging and psycholinguistics, "the discipline which is able to interpret events defying logical observation and which makes it possible to measure state of mind in terms of both quality and quantity" (Belli and Sagrillo 2000).

4. MODULE III: COLOR AND FASHION

The Fashion Module opened with a discussion of the relationship between colors and personal beauty, in the sense of a person's coloring (complexion, eye and hair color) and make-up, presented by one of the most important Italian make-up specialists. Then an image consultant introduced colors to be worn based on the 12 different color types of the "Color For All Seasons" system.

But while these aspects enhance the personal history of individuals and their aesthetic relationship with color, fashion on the other hand addresses itself to an undifferentiated public, united by the same choice of the imaginary. So what kind of imaginary qualities does fashion put forward? Lots of different ones: some collections present an emphatic and

aggressive style, others a sumptuous and exuberant one, or a vague and soft one, or maybe a decorative and vivacious one.

In our opinion students do not need to learn to reproduce the trends of the moment but rather to understand how and why these trends originate, who starts them, and which colors, surfaces, materials and finishes best represent them. By thus combining a theoretical understanding with practical work, because color has to be intimately experimented with as well as understood, they can hone their perception and sensitivity to its numerous inflections.

The fashion system is the maximum expression of the post-modern period and is characterized by a growing fragmentation of culture and an ever-greater importance attached to the symbolic and aesthetic components of products. A historical awareness linking trends to the past which generated them has been replaced by a culture of sound bites: which means breaking up the old into de-contextualized fragments which are then put together again as desired. However we feel that it is very important for students not to lose contact with the course of events and with the material, cultural and political motives which determine them. Therefore a good number of lessons analyzed the changes that have taken place in the taste for colors over different periods of time, since knowing and understanding the past is an indispensable premise for designing the future.

The practical work in the laboratory produced a series of historical *palette*s, which exemplify the main ranges present in the different periods. Much attention was devoted to the twentieth century, which is continually remembered and renewed by fashion collections, and each ten-year period was analyzed in detail.

The historical study and its application in the practical work was followed by the analysis and visualization, using palettes of color combinations, of contemporary color trends with a view to designing fashion trend color books. As is known these are not the result of ordered rules of logical structures based on perceptual and quantitative elements but are rather born of continuous reflections on the symbolic, communicative, emotional and synaesthetic dimensions of color, on its cultural roots and the tensions which arise between local and global expression. From the rational and functional language of the "modern" with its grammar of space and its syntax of combinations (Luzzatto and Pompas 2000), with fashion we have moved into the emotional language of the "post-modern", which acts below the levels of consciousness.

The teaching methodology we used aimed to "change the way students observe things", to open up their minds to the contemporary in its visual and chromatic expressions, comparing significant events in art, in cinema, in fashion advertising and in design. Good training which sensitizes them, and constant practice which increases their attention to color and its many variations of tone and communicative value.

The students visited the most important textile fairs in the business sector: "Moda In" and "Pitti Filati", where the latest fashion color trend books are presented to buyers who come from all over the world and, at the end of the module, they created their own fashion color trend book, presenting their own personal choice of shades arranged according to professional criteria.

5. MODULE IV: COLOR AND DESIGN

Design was not a key module but a supplementary area of the course, introduced in order to present space as a series of dynamic relationships between colors and also because many fashion houses today have their own lines of furnishings or else have a considerable number of licenses for the same. They are therefore present in the market with objects that have to maintain the imaginative content of their respective fashion products.

Objects and interiors, quite apart from their intrinsic qualities, are called upon to acquire meaning and value through a color project able to give them identity. For this reason the students experimented by relating the colors of the various components of the interiors, while taking into account the surfaces, the finishes and their reflection of color in natural daylight and in artificial light.

The basic elements of lighting design (photometry, the science of vision) and the fundamental principles of designing lighting for different kinds of interiors and spaces using appropriate technologies completed this module, introducing the notion that today light is a true material of design.

The students were taken to visit Villa Menafoglio Litta Panza in Varese (Italy), which houses the most important private collection of minimal and environmental art in the world. There they were able to see and appreciate "the works that Dan Flavin, Robert Irwin and James Turrel created especially for the villa. (They saw how) Irwin and Turrel create a kind of dialogue between the natural daylight and the volumetric shape of the rooms and how Flavin immerses visitors in a total enfolding color that they cannot get away from: places where neon lights blend and diffuse intense radiation that breaks down the definition of the areas and confuses perception. A color that is completely devoid of shape" (Luzzatto and Pompas 2002).

Since the amount of time devoted to design was reduced to a minimum, the next time we will be offering two courses: "Fashion Color" and "Design Color".

6. MODULE V: EXHIBITING

In the last module, the exhibiting module, the students took part in the preparation of 600 square meters of space that the ADI had made available for the presentation of the new profession to the city. They exchanged ideas on the existing furnishings, colors and lighting, in order to try and make the most of them and they prepared the props for the closing performance, by the *corps de ballet* "Pulsar", who performed an acrobatic dance on the theme of color to music composed by the DJ Trigger. For the occasion the film director Laura Del Zoppo showed the film that we are presenting to you today.

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Aspects of colour communication between different paint materials

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ABSTRACT

The big quantity of colours and paint materials is setting demands on different needs. Colour systems have been developed and are necessary to be able to communicate and produce all this colourfulness. We have to find solutions for visual agreement between different paint materials when we want them to be perceived as "the same colour". Demands on colour accuracy have increased and today we only accept small colour differences. This paper will show different examples of how you can work with and solve these different aspects of colour appearance.

1. INTRODUCTION

Different archaeological findings tell us that humans have always been aware of and using colour as a visual sensation. Colour as a visual phenomenon has been fascinating people in all times. Colours were probably first used for decorative purposes 150,000 or 200,000 years ago. Paint materials were made of plants and earth resulting in a very limited colour scale. The ability to distinguish different colours was a necessary asset in the fight for survival. Colour helps us to identify different objects, and colour informs us about inedible plants, access to water, distance, whether fruits are ripe or unripe, etc.

In the past it was expensive to paint interiors or dye textiles except in certain natural colours. Objects received their natural colour, which was determined by the availability of natural pigments. The possibility to influence our surroundings with regard to colour has increased considerably during the last hundred years as a result of the increasing availability of synthetic colouring materials. We now use colour everywhere as an environmental factor similar to shape and pattern. We are no longer confined to nature's limited colour scale. We can chose colours more or less at our own delight. However nature doesn't consist of unlimited resources and we have to restrict our use of environmentally harmful paint materials and harmful pigments, like cadmium and led, to protect our world.

2. COLOURS MANY DIMENSIONS

Because of ever expanding possibilities to influence and control our colour environment, knowledge about colour has become more and more important. The enormous variety of colours can even be a disadvantage and may end in a big chaos of colours. We will have difficulties in orientation and we might feel sick because of over stimulation through colours. Colour planning which is more consciously done is indispensable for a well-oriented society.

There are many different dimensions of colour appearance to consider when you look at a surface and paint material, like chosen colour, matt or gloss surface, texture, transparency, shades, patterns, reflections, metallic, viewing distance, light conditions.

The texture of a colour (Sisefsky 1994) is one factor complicating the colour appearance. If you look at two differently textured textiles that have the same colour they look different, because the patterns between the threads will cause small parts of light and shade. These will give different textures when you look at the textile in close distance.

Cesia is another visual percept of a colour:

Cesia is the name adopted to designate the aspect of vision that has to do with the perception of different spatial distributions of light. Light interacts with objects and it can be absorbed, reflected or transmitted; in turn, reflection and transmission may occur regularly or diffusely. These are physical matters. Now on, the human visual system perceives this decoding and interpreting it as visual signs that carry information about certain qualities of the objects around: level of lightness or darkness, degree of opacity, glossiness, transparency, translucency, matt quality, etc. This kind of visual percepts are the ones just covered by the generic name cesia. (Caivano 1997: 136)

The tincture of a colour is also an expression for the colours' many dimensions that were used in heraldry:

With the increased attention being paid to the geometric attributes of appearance and the recognition that these, like colour, have many dimensions, it would be useful to have a word like tincture, in its heraldic sense, as part of our everyday vocabulary.

The Art and Science of Tincture would deal with all aspects of appearance —metallic lustre, gloss, transparency, redness, chromaticness, tonal value, smoothness, hairyness etc. Colour theory would be just a part of the bigger picture offered by tincture theory which would show how all aspects of appearance are different from or related to each other. (Green-Armytage 1993: 252)

2.2 The colour appearance of different paint materials

In industrial design you often work with different materials like plastic, steel, and textile, and you want them to be perceived as "the same colour" even though they are based on different colour materials, such as dye and pigments. How can you solve this problem? How can you judge the colour without paying attention to the different textures?

When you are working in interior and exterior colour design there are today a lot of different paint materials to chose from. How do you deal with the different colour appearance of these different paint materials and how do you communicate? How can you compare the colours on, for example, a textile with a colour sample and get a visual accordance?

The appearance of a facade surface is due not only to the colour. Other visual attributes like gloss, depth, transparency and textures are also important for the expression that the surface gives us. This thesis deals about painted façade surfaces of plaster and wood and how the appearance of the surface is influenced by the type of paint and how it is applied. The appearance of a facade surface is not constant. It changes temporarily with changing in for instance light and moisture and it changes by time when the surface ages. All these aspects of appearance make it possible for us to recognize the material of a surface and judge its quality and I therefore call them the *materiality* of the surface. (Svedmyr 2002)

Svedmyr has studied plaster and wood samples treated with different paint materials. The appearance of the samples was described both as new painted and as aging after some years outdoor. He has also tried to describe the different visual attributes that constitute the appearance of a surface, which has been an important item in his studies. One background to his project has been the widely spread conception that different paint materials (with regard to the binder) will give the painted surface different appearance and that an experienced eye easily can distinguish between surfaces painted, for example, with linseed oil paint and those where acrylate paint had been used. The conclusion from this project has shown however that the appearance of the painted surface, both new and aged, depends not only on the binder of the paint material but on a complex interaction between a number of the ingredients in the paint material.

2.2 The visual comparison between gloss and matt

Gloss is another important visual attribute of a painted surface. It is essential to and influences perception in design and architecture. A glossy or matt finish can have an important effect on the general impression of a paint material of a given colour. The impression also depends on the viewing angle.

> Based on the phenomenological concept of gloss as an independent visual quality, we can formulate the operational definition *that two objects of different gloss have the same perceived colour if they appear to be equal in colour when viewed so that the appearance of the difference in gloss is eliminated.* As soon as the viewing situation is changed we perceive the two objects to be visually different and it can be difficult to separate the appearance of gloss from that of colour because the two phenomena interact with each other. (Hård 1988: 5)

It is very important to reach visual agreement as far as possible between the matt and glossy surfaces. With a background of visual research studies, and many years of experience and knowledge of colour control, the Scandinavian Colour Institute AB has found good conditions for visual agreement between matt and glossy surfaces so they are judged to have the same visual colour. This method agrees well with measurement results.

In this case we are working with matt and glossy colour samples, which are placed horizontally, edge to edge, in a light box. The figure below shows the conditions for the light box. The illumination must be good and the light must be placed behind an opal diffuser vertically placed against the colour samples. The walls in the box must be white. The samples are viewed at an angle of 45° so that the evenly illuminated white light box surface is placed in the specular angle for the glossy surface. The reflection of this white surface then corresponds to the reflection of the white illuminated sphere wall in the t/8 measurement geometry. In the measurement and control of glossy and matt surfaces, the t/8 measurement geometry is used; diffuse illumination, measurement angle 8° from the normal to the surface, specular component included, sphere diameter approximately 20 cm. This is currently the accepted industrial standard.
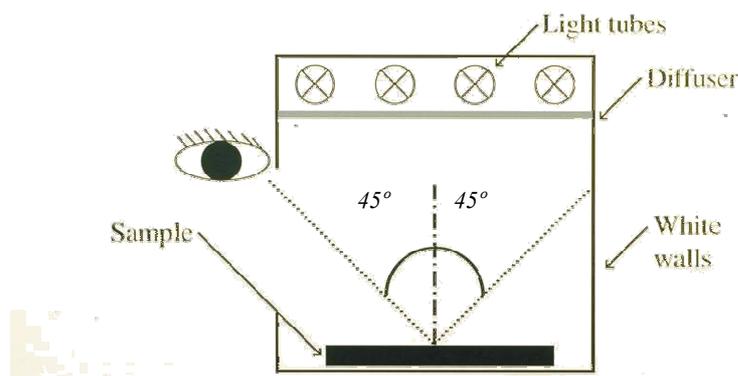
Figure 1. Conditions for the light box.

3. COLOUR ACCURACY

The wide range of colours and paint materials will lead to ever greater demands for precise knowledge on the part of colour designers. Demands on colour accuracy have increased and only small colour differences are accepted today. Accurate colour communication is important to almost all industries. Designers and developers who select a colour need tools to communicate this colour accurately to producers. Product development from idea to finalised product or environment entails a chain of colour communication that has to be based on a visual colour system. The process from colour appearance (the designer) to production consists of the following elements: the perceptual idea, the visual analysis, the designer's choice, documentation, communication, production and control. Bad colour matching will give customers the impression of bad quality of the product itself.

Colour has become an even stronger factor than before in different fields like graphic design, corporate identity, or marketing where the colour and paint of a product can be decisive of its fate and success. The colour designer is looking for experience and knowledge from colour research, which can be used in colour design. Colour research in areas like colour and paint, colour combinations, colour preferences, colour emotions, etc. have already gained a more prominent role and the demands on the practical use of colour research are increasing.

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Color theory in infant education: Practical experience

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ABSTRACT

The following poster presents part of a teaching unit carried out in 2003 with children between the ages of 4 and 5, at the Alquería School in Granada (Spain). By playing and designing clothes, the students easily became familiar with certain aspects of the theory of color. They were able to relate those aspects to their environment and to their own lives.

1. WE ARE CLOTHES DESIGNERS!

Gonzalo is a four-year-old boy. He loves to dress up to play at imitating people, just like the other children at school. This was one of the reasons for focusing our work on imitation games. At these early ages, imitation games, or symbolic games (characterized by pretending, playing out, and imaginatively recreating events, people, and objects that are absent) are a key ludic cornerstone for learning (Martínez 1998).

We decided to play at "Being Clothes Designers" so our teaching unit would motivate the children to remain attentive and active during our proposal's development. Designing clothes would enable us to:

- Use body expression games and logical construction and deconstruction games to provide the children with vital experiences.
- Analyze certain aspects of the color theory with the children, relating color to their own life and context.
- Analyze the creative process of several contemporary artists who have to do with clothes design, thus providing the children with significant experiences.
- Study the role of clothes design in our past and present history, relating it to the children's life and context.
- Use the proposals to promote descriptive, thoughtful, critical and understanding skills, thus contributing towards the children's individuality, self-discovery, and their own production.
- Give rise to artistic productions that are both thoughtful and creative.

How could we use the theory of color with children of this age in a way that would bring about significant learning? Our aim was to introduce them to concepts related to the physical and expressive attributes of color, and to mixing primary colors to make secondary colors. To achieve this, the children had to feel motivated to adopt a thoughtful and critical attitude towards the contents we offered. They would have to relate them to their prior cognitive structures, and to their own personal experience.

Considering the children's inclination to play at "being princes", "knights", and "princesses", we decided to use this tendency to work on color theory with them. We would play at "being knights errant" and we would design our own knight's clothes. To do so, we would use several procedures: first, we would listen to the story "The knights' shirts". Next, we would draw what had happened in the story, and then we would make the clothes that the knights wore. Finally, we would act out the story's principal characters in a play.

This process would allow the children to develop an inquisitive attitude towards the proposals, find independent solutions, become interested in the role that colors play in their environment, value and know themselves, participate actively in the proposals and collaborate with each other in group dynamics, among other attitudes.

## 1.1 Proposal one: The knights' shirts
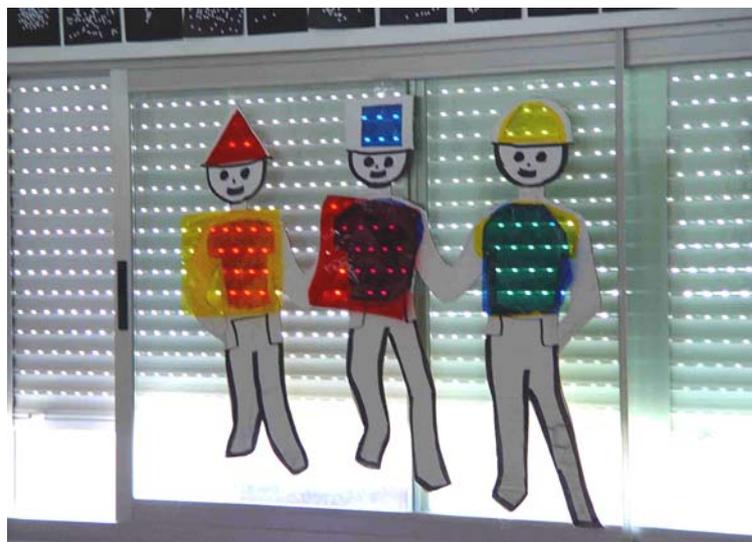
Figure 1. Picture of the materials used in the play "The story of the knights' shirts".

"Once upon a time there were three knights who always like to be very well dressed. One of them was named Red Knight. Do you know why? Because he was all red: his clothes, his face, his hands, his shoes... all of him was all red. He was the most dangerous knight of all. You had to be very careful with him because he was always very, very nervous. But, do you know what? Red Knight was always in love! He was always falling in love. He even fell in love with the flies that flew past him! That is why he was always very happy, even though he was known as the most dangerous knight in the area.

And do you know who Red Knight's friend was? Yellow Knight. He liked Red Knight because he was a very cheerful person too... and a little bit nervous, like Red Knight. People said that Yellow Knight had a great fortune, but he never talked about that. He preferred to go horseback riding with his friend Red Knight. But do you know what? Wherever they went, and no matter what time of year it was, they always complained about how hot it was.

These two knights were very friendly with Blue Knight. The called him that because he was all blue. Even his moustache was blue! Blue Knight was always bundled up and complaining about the cold. Unlike Red Knight and Yellow Knight, he was very peaceful and calm. That is why Red Knight, who was a bundle of nerves, like to be with him. Blue Knight helped him to calm down. But, do you know what was the matter with Blue Knight? He was always sad and in tears! Only Red Knight and Yellow Knight could cheer him up with their happiness and their jokes. And do you know why he cried? Because he knew that one day he would have to leave his friends. And because Blue Knight was a very sincere person, he showed his sadness and feelings all the time.

Figure 2. A drawing by Alejandro (4 years old) after listening to the story about the knights' shirts.

And finally, the day that Blue Knight feared arrived. The three knights had to go their own separate ways. That day, even Red Knight, the happiest knight of all, let a tear drop.

Before leaving, the knights decided to give each other something so they would always remember the happy days they has spent together. They decided to give each other their clothes: Red Knight gave his red shirt to Blue Knight, Blue Knight gave his shirt to Yellow Knight, and Yellow Knight gave his to Red Knight. And do you know what happened when they put on the shirts?

When Blue Knight put his friend's shirt on, the red color of the shirt mixed with the blue of his own body and the shirt turned into a purple shirt. And when Yellow Knight put on his friend's blue shirt, the shirt's blue mixed with his body's yellow and the shirt turned into a green shirt. And when Red Knight put on this friend's yellow shirt, the yellow color of the shirt mixed with the red of his body and the shirt turned into an orange shirt.

And so, the three knights went their own way feeling happy that a part of each of them had mixed with their friend's colors."

After listening to the story, the children were proposed to experiment with their drawings to find out what happened when they mixed the colors of the knights' shirts (Figure 2). The purpose was to have them experiment with mixing the colors, so that later they could apply them to the clothes they designed.

1.2 Proposal two: Mixing and playing!

With this activity, we proposed a game in which the children would play at being clothes designers, so they would make their own knight's clothes. They made the clothes with cardboard, joined the pieces together with wool (Figure 3), and printed them with foam rubber stamps. That allowed them experiment with obtaining secondary colors (Figure 4).

While they mixed the colors, they started to talk among themselves about the colors of the knights' shirts. We used this to help them to relate those colors with the colors of their own clothes, their parent's clothes, and the clothes of their family members and friends. Next, they analyzed whether these colors existed in other areas, such as Nature or industry, and thought about the differences between the colors of these areas. The outcome was an experience during which they were exposed to colors, experienced them, and thought critically about the nature of colors way.

When the children finished making the clothes, they were proposed to improvise situations, imitating the characters in the story. To do so, they would have to remember what each knight was like: whether he was happy or sad, and so on. Thus, they would think about the

Figure 3. Making the clothes.


Figure 5. The children dressed up as knights.
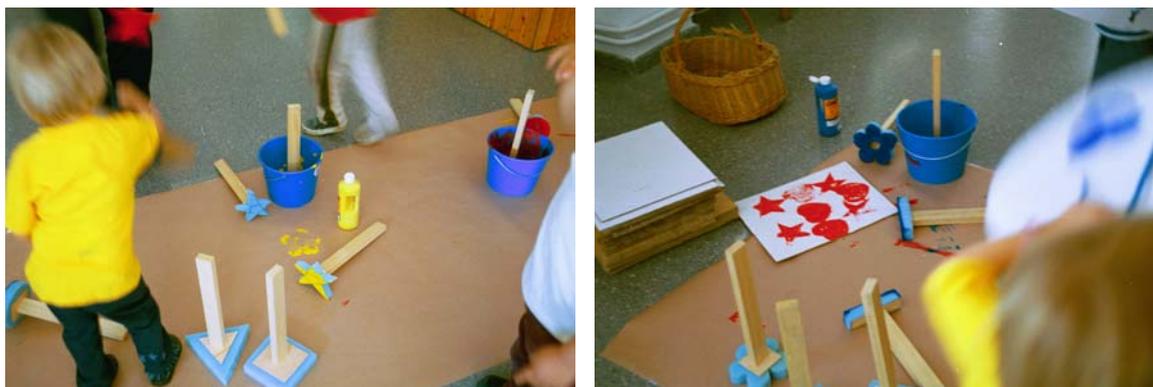
Figure 4. Mixing primary colors with foam rubber stamps.

expressive and physical qualities that are associated with the primary colors. To develop this game of imitation, the children dressed up (Figure 5) and acted out something that would define the character they chose to represent "to be in love", for instance. The other children would guess which knight they were supposed to be.

2. CLOSING, BUT LEAVING A DOOR OPEN

Experiences such as this highlight the need to reconsider the importance of having children approach color analysis from an early age. At the same time, it opens a door to reflect on the status of infant education today. To what extent can we work with the theory of color, color-light, color-pigment, reflective objects and the morphology of the eye with young children? Can we use these contents to create a context for critical thought and analysis on the part of our students? As we have seen, "where there is a will, there is a way". Education and a child's smile are at stake. Shall we make the attempt?

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How "to paint" with words: Talking about color in learning situations in graphic design

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ABSTRACT

This analysis is circumscribed to the verbal discourse about color in situations of graphic-language learning. It does not deal with the teaching of color theory in graphic design, however, but with the linguistic descriptions that involve chromatic aspects in pedagogical interactions. Only the verbal interactions resulting from the review of students' works in the stage of evaluation is considered as the subject matter of this analysis. We start from the hypothesis that verbal language endows the student with an essential tool for the conceptualization of his graphic production. Color, one of the factors that are evaluated in the practice of design, is a topic of discussion and analysis in the verbal utterances about the project. The quasi-pictorial descriptions of the chromatic resources employed emerge recurrently in the dialogues about the students' proposals for graphic projects. Not only they show their work to the teacher, but also that action of exhibition is accompanied with a verbal argumentation about the adopted choices. The verbal description depicts —actually "paints"— with words the piece of design. It does not simply exhibit the design, but makes it explicit. That new "coat of paint" reinterprets the project, assigns values to it. Also, this "coating", or layer, demonstrates in the concrete practice the degree of acquisition of concepts, theories, uses and cultural values assigned to color by the students.

1. THE GRAPHIC PROJECT: THINKING, SAYING, MAKING

As to the arts generally, they are for the most part concerned with doing, and require little or no speaking; in painting, and statuary, and many other arts, the work may proceed in silence... (Socrates, in Plato's *Gorgias*, 392 b.C.)

Socrates' opinion is widely shared by the people dedicated to graphic production. As a matter of fact, in these disciplines the project (object, product, etc.) has a value in its own; it could never be replaced by a verbal explanation of the intentions, aims or other considerations. The graphic language and the verbal language do not have the same perceptual impact. To show a colored image, obviously, is not the same as to explain how colors habe been applied. In front of a red signal, for instance, the most primary and immediate feeling is the visual impact of the chromatic sensation. The conceptualization appears later. In the case of the verbal language, the sensation arises mediated by the reasoning of the user, who, being able to join the concept to which the word "red" addresses, will put color to this surface in his imagination with some of the possible red colors stored in his memory. If the visual image, as compared with the verbal text, is always characterized by being polysemous —because of its capacity to generate and multiply meanings—, words are not univocal, as well. The example of the red signal would be one of the cases in which the quality of redness is more polysemous when evoked by the verbal language than by visual signs. The verbal text and the image *say* something different, and the ambiguities that they reveal are also of a different

order. One of the causes is that they are two different languages that activate specific competences, confront presuppositions, strategies and "contracts" of reading that are also different.

With regard to the possibility of inter-translation, according to Garroni (1972), natural language and image are two systems of meaning that maintain a separate relationship between expression and content; when the passage from one to another is intended not only secondary unpredicted meanings are generated but also the irreducible character of certain portions of content becomes evident. Moles (1981) asserts that there is no illustration possible of a text by a graphic, even when an adequate comment of a series of images by a literary text can exist. What Moles calls "unlikely accident" is the possibility of transmitting identical information in both languages, and it can only be verified when recognizing both semantic (denotative, translatable) and aesthetic (emotional, connotative) equivalences in a message. The translation will be achieved when both structures evoke the same connotations for a wide range of readers. However, it is appropriate to maintain an essential distinction between *translation*, as a perfect analogy, and *interpretation*, as a partial resemblance (Kibédi Varga 1989). The interpretation characterizes the relationships between word and image at the object level, while the translation might possibly be achieved when the relationships between both levels are thought in a meta-level.

Between a color sensation, as perceived by a human subject, and the evocation of a color by means of the verbal language there are, obviously, zones of irreducibility, "silences", gaps. In this regard, the recommendation by Deleuze and Guattari (1980) of not reducing without valuable remnants what is visible to what is enunciable can be very useful for the education in the field of graphic design.

2. ANALYZING THE DIALOGUES ON COLOR

The designer has to use color in an objective way, while the painter, instead, uses color in a subjective way. (Munari 1976, my translation)

The quotation expresses one of the presuppositions —almost an obviousness— in the culture of the future designers. The necessity of paying attention to the communicational and functional requirements, beyond the pure aesthetic subjectivity, is a key in the education, in the justification that the students provide and, consequently, in the evaluation of projects.

2.1 Clarifications about the methodology

The work of our students in the design workshop has a silent phase, but in parallel there is another instance that opens the interchange, promotes auto-reflection and analysis. The dialogue in the situation of evaluation of the student's works —in individual and collective corrections— is the kind of interaction selected to investigate how the word of the teacher redirects the project, because its modality of verbal intervention has incidence both in the learning process and in the promotion of students.

The corpus of analysis has been collected by recording the dialogues between teacher and students in the successive individual corrections of the graphic projects, that are previous to the final evaluation. The universe of analysis encompass teachers and students of the Graphic Design Workshop courses at the School of Architecture, Design and Urbanism of the University of Buenos Aires, in Argentina. The recollection of the corpus began in 2002 and continues at present, and is expected to continue in the three levels and in different chairs in which the courses are taught. The interactions are transcribed taking into account the signs of

orality that are typical of the dialogue. The non verbal behavior (gestures), registered by on-site annotations by the researcher, is included by means of marginal notes.

The analysis of the corpus allows for the formulation of categories that are useful to shed light on the ways in which the teacher intervenes to orientate the students in these interactions. In what follows, only a part of this project will be exposed, which is concerned with how (with which criteria) the use of color is corrected in these dialogues. The material transcribed corresponds to the first level of the course. Because of lack of space, the most pertinent fragments of each interaction have been segmented.

2.2 The defined strategies (analytical categories)

The analysis of the corpus allows for the typification of three strategies —with different functions— of the teacher's word in the dialogue. The teacher makes corrections by asking *questions* (1), by *reformulating* theoretical aspects (2), and by proposing *resolutions* (3).

1) Questions are intended to call the attention on problems or errors. They are not questions in strict sense —to obtain an answer about something that is unknown— but the typical "didactic questions". Even, they can be formulated without interrogative intonation. The teacher asks questions to hear an answer that he already knows and that he presupposes that the student should know. As a posterior effect, these questions seek for new proposals in the concrete work on the part of the students. They are related with proposals to experiment, play, and try new solutions. They incite to search, stimulate the research. A fragment is transcribed to exemplify this function:

TEACHER: Is it black?
STUDENT: It is ... ah ... It is black. Like in a tone withhh ... did you say? with blue. With black ... like ... all that melts ... ah ... things.
TEACHER: I am tired of black. Black. Black. Black. Black everywhere. Only remains to be black here. Black in the cover of the folder. *[Pointing to the pieces of design while he speaks.]*
STUDENT: Yes, everything is black.
TEACHER: Look all the colors that this guy has brought. *[Speaking about the work of another student.]*
STUDENT: Uh! *[Laughs. Silence.]*

2) Reformulations: During the corrections, the teacher also reformulates some parts of the dialogue in terms of the disciplinary language. The purpose is to consolidate the learning of certain concepts already taught, even when they work subtly as justifications (appealing to the voice of the theory) of the teacher's own corrections. The teacher does not rely on his subjective criteria; instead, his intervention relies in the consolidated disciplinary knowledge. His individual voice incarnates the voice of the graphic design community, which endorses with authority and validity his own words. In the following example, the teacher focalizes on two concepts: chromatic palette and legibility:

TEACHER: As a basic problem: chromatic palette. There, the palette that you are using is so, so, sooo next one to each other that ... ah. Did you change this? How was it? White and black?
STUDENT: White and black.
TEACHER: And why did you change it?
STUDENT: Ahhh... I don't know
TEACHER: How do you manage to solve this? Eh, I don't know. Modify the photograph until you reach the color. But you are not going to read this way. Do you understand?

3) Resolutions give "authorized" teacher's answers. They propose solutions of a conceptual and graphic kind, including the reformulation of the piece of design. Resolutions create a movement that is contrary to the questions, because they are intended to reduce the options, to close the theme. They are mainly produced by the students in their verbal interventions or graphic proposals. Sometimes, resolutions are related to questions formulated

by the students, looking for the "right" answer. Or they appear when the teacher judges that the time for experimentation on the part of the student is over. The teacher considers at that moment that an intervention of the type 1 (question) does not give an orientation to the student, or might produce anguish to him. Some of these resolutions begin, apparently, as formulations of the type 1, but they are just rhetorical questions, asseverations. Resolutions are soothing answers; they give security both to the student and the teacher. The function of resolutions would be to assure the teacher that the final student's work will meet the requisites. However, they have a negative side, because they generate a certain discomfort on the teacher's role. The teacher is afraid of being "trapped", because if the student uses the solution provided by him in the final work, that would be inappropriate, but he could not disapprove the student, either.

TEACHER: And what is this? The coast of Galicia with oil?

STUDENT: *[Laughs.]* No ... Is that it is ... ah...

TEACHER: Everything black. Stop with black. No, no black, no black here. I am in an aquarium. I am seeing sharks and suddenly I see an oil slick, floating. Fucking. At a certain moment I began shaking.

STUDENT: *[Laughs.]*

The following fragment shows how these modalities of intervention are combined and may appear in the same sequence: a *question* (1) at the beginning, then a *reformulation* (2), and finally a *resolution* (3):

TEACHER: Stop. Stop. Stop! Here we are. Here we are. Here we are. What kind of problem do you have here? And here? (1)

STUDENT: The legibility of the characters.

TEACHER: Basic! Basic! Legibility (2). If this goes in white it would be better, isn't it? You finish here.

STUDENT: And here?

TEACHER: Well, here is a matter of beginning to fit in the photograph. Perhaps, this photograph, if you enlarge it a little bit ... the black surface of this car is going to be bigger, is going to reach around here. You quit this trash, which serves for nothing. None of black here. And the black surface of the car. You need adrenaline. If this doesn't fit, perhaps I have to put it in two lines. With some little play... (3)

Words cover the object in order to explain the student's intentions and purposes in his chromatic decisions, or to make them objective. This is possible because it is presumed that the selection is not made by chance, but follows certain disciplinary criteria, which will be possible to evaluate by the teacher. In correlation, the analyzed examples show how the teacher indicates in his corrections, by means of different strategies, which competences in the use of color are expected in a student of graphic design at that level of formation.

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Making color: Pictorial art training for environmental color design

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ABSTRACT

The current experience refers to a workshop I held at the university, which for the first time organized a workshop about color and about environmental color design. It is important to educate students to color analysis. The aim of the course was to work on colors in the environment: students had to gather chromatic information on urban spaces, proving their ability to see and identify colors linked both to nature, landscapes, and street furniture. To this end, an exercise I had designed entitled "Let's Invent Colors" proved to be very useful. Each student created his own palette not according Itten's system of "subjective colors" but with the creative attitude of a painter or the scientific attitude of a researcher who must trace back the color composition formula after making "his own" color. The above exercise was enthusiastically performed by approximately 70 students. The outcome of this course was shown in March 2004 during the exhibition "Experience in Color, between Expression and Design" promoted by the Councilor for Urban Quality of the Municipality of Genoa and by the University, within the events organized for Genoa, European Capital of Culture.

1. FOREWORD

This conference offers me the opportunity to further elaborate on the issue of color and painting, which is part of my constant activity aiming to work out new research and communication methods about color. The final goal of this research is to make a quality leap forward in a new design approach well beyond my usual "routine" work. Against this background, I will describe the methodology followed in a color course I conducted together with Professor Luisa Cogorno, Director of the Design Workshop at the University of Genoa, School of Architecture, first year of the Degree Course for Industrial Design. The educational and training aims of the course were the following: development of technical and experiential skills; development of a higher sensitivity toward the environment, namely the ability to perceive, invent, intervene on the environment through colors; regaining of the symbolic meaning of an environment color, which thus becomes sensory, alive, and involving, if we are able to perceive it or design it (final goal of the course). Hence, color was not only taught from a technical-scientific point of view, but rather through its pictorial expression, namely by working out the whole color range through *experience*, in order to obtain subjective contents arising from one's own creative skills and perceptions.

When referred to the more limited context of the design course, the value of the above formula coincides with the latest design trends, of a greater attention to the artistic value of a product, even through its "color quality".

2. ITTEN'S LESSON - COLOR, PAINTING, PEDAGOGY. COLOR AND CREATIVITY

My reference to the teachings of Johannes Itten is clear, himself a painter and master of Beaux Art as well as appointed by Walter Gropius to teach at the Bauhaus school. This is an important reference, because it shows the goals of his teachings, also addressed to the world of industrial production. In his famous and fundamental work entitled *The art of color*, Itten (1965) does not only employ his didactic principles on "color rules", but he also draws on his studies on historic, modern, and contemporary painting.

For example, he examines the colors of the "Coronation of the Virgin" by several painters, like Charenton, Rembrandt, Seurat, Picasso, Grunnewald, Renoir, Cezanne, Van Eyck, observing that the blue-greens, red-purples or blue-blacks represent a pictorial interpretation of chromatic forces leading to a sum of sensitivity which goes well beyond any historic succession, even joining the past with the present.

Therefore, his intention is to "read" —through color— those paintings that in the past had fascinated him. According to his words, chromatic laws that he had recognized in works of art are not affected by time, and today they have the same value of yesterday; also, the power of expression attainable with colors will always play an essential role in the creative process.

In particular, in his teachings and pedagogic proposals, I have not only found his technical-scientific exercises to be very useful, but in particular his exercise on subjective color, or, better said, subjective chromatic agreements, which attaches even more importance to the sensitivity and individual perception of each student.

All this has suggested to me that, as part of a design workshop, a fundamental element to stimulate color involvement would be to link it to a personal and conscious creation process.

Applied color, which is a typical feature of design, is normally based on industrial classifications, from which the designer selects the most suitable colors. To interfere, from a didactic point of view, with this generally accepted convention, meant that each student would have to "create" his/her own color palette. However, this "creation" was not to be confined to some early stage in the subjective pictorial process, but chromatic dosages had to be programmed and fully analyzed. In this way, a *repeatable* color palette could be produced, which was developed through inner personal choice and out of the pictorial process of each student.

It is important here to mention the school background of participating students: about 10% of the 70 students (aged 19 to 22) had attended art school. Hence, one more reason to help them stimulate creativity and their propensity for color, starting from their own personal sensitivity.

3. CLASS ITINERARY. "LET'S INVENT COLORS". COLOR & DESIGN. COLOR AND HISTORIC AND CONTEMPORARY ENVIRONMENT

Following an introductory theoretical and scientific part on color and all its applications in the world of art —from painting to architecture to the historic color in urban environment, and color design in contemporary environment— we began to "produce colors", starting from the discovery of color matches and contrasts, by cutting out collages or through painting.

Even the color wheel —which is a standard cognitive exercise— was intended to spring out of a practical painting process.

Further, water color techniques were developed, according to Ulm's school and Klee's poetics, which best describes light/color transparencies.

However, in terms of novelty, the most involving exercise was the "Let's Invent Colors" one: each student created his/her own palette, not only following Itten's "subjective color" system, with a painter's creative attitude, but also with a researcher's scientific approach, who, after having produced "his" color, has to trace back its chromatic composition formula.

It is interesting to observe the different color palettes —featuring nine different color squares— expressed by each student: in some the mid square is the lightest and brightest one, in some others it is the darkest and most composite one. Generally speaking, all palettes are highly variegated. In some of them, a good tone outcome was obtained, or a contrast. In any case, they are all highly elaborated with different percentages of color (Figure 1).

"Let's Invent Colors" is an exercise that for sure *does not* invite students to refer to classified color palettes *pre-arranged and offered to our personal sensitivity by industrial production*. Conversely, students become owners of the result of a creative experience, which provides an alternative to standardized behavior.

Some significant comments by the students:

"In certain areas, and design is one of them, a good knowledge of color is fundamental, even essential, in order to judge a project complete."

"However, the study of color is also a form of personal enrichment."

"Everything is more true if it has color on it, each object represents something different by merely changing its color."

"It is impossible to have an objective knowledge of colors. Our eyes are not at all identical. And the expressive power that we attach to colors is above all personal, hence they are not universal."

"However, everything we perceive is referred to a chromatic contrast, hence it is a necessity."

4. CONCLUSIONS

All this is important to make painting practice more valuable. In this way, it may acquire a more active role, because it is based on a creative and emotional experience, hence promoting our ability to better see what lives around us through color.

Other exercises focused on spatiality and color and material synesthesia. In any case, the final part in which, as mentioned at the beginning, students became the real protagonists was the one on "Color Around Us". They analyzed and then fixed with photos the colors in nature, colors and the urban environment with chromatic perceptions and related environmental design projects.

A really extensive range of highly individual contents and research works was thus collected, where color was perceived as an active and dynamic element which is part of a new and conscious dialogue with the external habitat: the value of natural light acting on colors and on the shades of the environment depending on the time of the day; the perception of distance; all concurrent meanings of our contemporary cities, representing a close mesh of history and modernity, as well as of contradictory aggregations.

The students in their works approached the issue of comparison between past and present environment, which at the same time offered them a different opportunity to enhance their knowledge and gain in-depth experience in these issues.

Within the same contexts, students were also able to tangibly link their work to Genoa, with its long and unique tradition of painted facades for which already in the past it was known as *Genua Picta* and "multi-colored city on the sea". Genoa, at the same time, provided a concrete and well-motivated setting to the above described research works.

This is indeed the important message I would like to convey, as a positive consequence of the contents of the Workshop on Color.

In conclusion, and also to confirm that every single issue we deal with in our research and study work is always closely linked with our personal experience and life, I would like to add here that at the conference "Color and Urban Environment", of which in May 2003 I was the coordinator, several different international experiences were presented in Genoa (by Karin Fridell Anter, Susan Habib, Tom Porter, Fannie Tosca) all of them on this issue (Rizzo 2004), which, in turn, were fruitfully used in the educational project I have just illustrated.

To further highlight the quality and the originality of the results, a big exhibition of the works was organized in the historic building Loggia dei Banchi. The exhibition entitled "Experience in Color, between Expression and Design" was organized by the Councilor for Urban Quality of the Municipality of Genoa together with the School of Architecture of the University of Genoa, as part of the rich agenda promoted in 2004, under the events for Genoa European Capital of Culture.

During the exhibition, students reinvented this historic venue of Loggia di Banchi through color interventions on the floor and with chromatic installations. They were prompted by this new experience in which they were allowed to use color with an artistic sensitivity and consider space as a 3-D element to be fully lived.
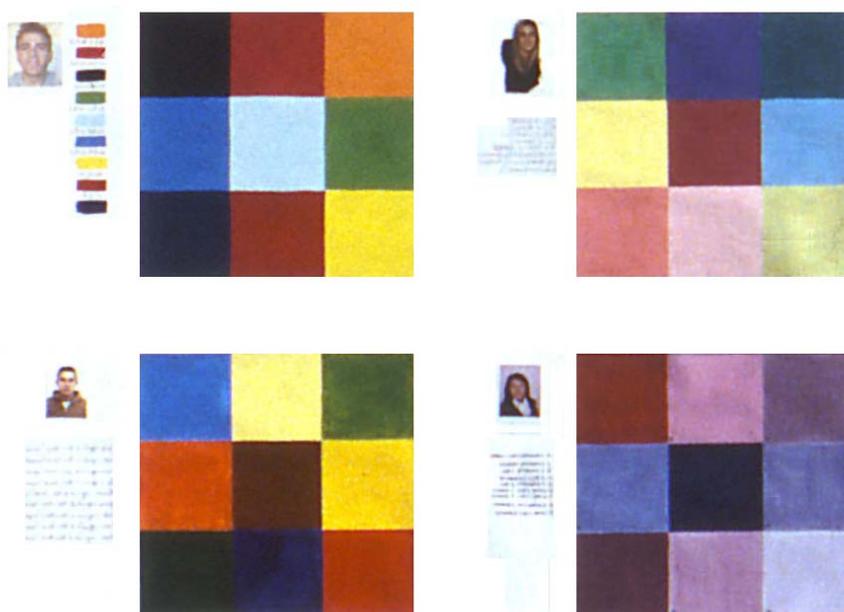
Figure 1. Dynamic variety of color tones in the "Let's Invent Colors" exercise.

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Color learning based on VLE-AD platform

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ABSTRACT

This article presents the theoretical basis and the structure that supports the virtual learning process on a collaborative environment for architecture and design: VLE-AD. The virtual environment is modeled based on the presuppositions of the problems based learning (PBL) and on the distance collaboration (Harasim 1989, Belloni 1999). The color nucleus is structured with learning activities in several modalities: contents, exercises and problems.

1. THE VLE-AD PROJECT

Virtual learning has been based specially on written language. Fields such as architecture and design, which are based on the development of the graphic-visual language, still search for learning environment models adapted to their specific needs. On this sense, the challenging goal of the VLE-AD, which was designed by Hiperlab of Universidade Federal de Santa Catarina, is to structure learning environments specially designed for fields that use graphic-visual language, concerning the pedagogical and technological aspects.

Currently organized into four big themes, which are shape, light, color and texture, the VLE-AD project is designed for students who are about to major or have already majored in architecture and graphic design or in linked fields searching for updating. This way, the VLE-AD activities emphasize the collaborative learning based on structures of cooperative processes, what means based on active participation of the students in the interaction and in the management of deviations (Fucks, Raposo and Gerosa 2002).

2. PROBLEM BASED LEARNING (PBL)

VLE-AD has chosen PBL as the axis of activities developed in the environment. PBL didn't properly constitute a theory. It constituted an educational approach based on the presentation of open and suggestive situations, demanding an active attitude and effort from the students to find their own solutions and therefore to produce their own knowledge.

To Pozo (1998), one of the best ways to make the students learn how to learn is the process of solving problems. Regarding the teaching based on the knowledge transmission, problems solving may constitute not only an educational content, but also a focus or way to conceive the educational activities. Teaching based on problems solving presupposes to promote the domain of procedures on the students, as well as the use of available knowledge to answer to questions from different and variable situations (Pozo 1998).

The distinction between the exercise and the problem also is related to the context of the task and the student that faces it. From the learning point of view, we could say that exercising is based on the use of skills or techniques already learned (which means they are transformed into automatic routines as a consequence of a continuous practice). The individual is limited to use a technique when faces a task and/or a situation already known, being solved by habitual ways and achieving also habitual results. Under a more open

perspective, a problem is a new situation or different from what has been previously learned, which requires the strategical use of techniques already known (Pozo 1998).

According to CCS/UEL the necessary instruments to use PBL are centered in the curriculum, tutoring group, tutor's functions, study themes, problems, acquisition of abilities, evaluation and management. In the group the students are presented to a problem previously elaborated by a commission, organized in an interdisciplinary character, composed by teachers and students. The problem must match the curricular content. The students shall formulate learning goals through discussion, similar to the ones imagined by the specialists.

Seeking to attend the specific needs of the architecture and design fields we stand out that the problem comprehension and the solving strategies will be necessarily measured by the use of instruments. Therefore, the graphic language, chromatic language and other codes that involve reading and production of images, graphs, outlines are pre-requirements for the environment. The PBL strategy intends to fill a gap in the learning process. Instead of working on the contents isolated, it is desired the problem situation to involve more than one content and to be approached under specific contexts, demanding an integration and adequacy of the theory to match each case being studied. To elaborate the problem presented in the environment, articles, reports, statements of designers and portfolios of professionals in the field have been analyzed.

3 THE COLOR LEARNING NUCLEUS OF VLE-AD

Each learning axis of VLE-AD color nucleus is based on three points: problem based learning (PBL), the potential of communication and information technologies (CIT) and the theory concerning the specific contents from each field (TC), as shown in Figure 1.
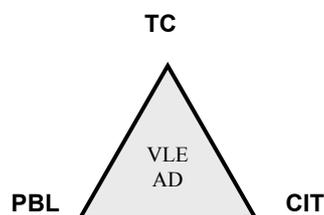

Figure 1. The diagram represents the theoretical basis of VLE-AD color nucleus.

Regarding the learning strategies, technological resources and tools, and the possibilities for interaction and communication, the VLE-AD is structured on four axes, which are: documentation axis, production axis, information axis and communication axis.

The *documentation axis* has image bank, text bank, didactic material, videos, animations, presentations, gallery for the work done by the group, allowing the student to recall the data at anytime. In the *information axis*, the supportive material for problems solving and collaborative activities are organized. There is a specific glossary about each content, which covers the theories extracted from extra studies, tips and complementary bibliography (articles, books and sites related to the approached subjects). The contents are structured in a flexible and interactive way, and can be easily accessed according to the student's interest, not depending on time or place.

The *communication axis* presents the tools that support the activities developed by the students in the VLE-AD. Therefore, e-mail, chat rooms and forums are available tools for dialogues and interactions between student/student, tutor/student, teacher/student and also

include the possibility to attach images. Stands out the fact that the 3D and 2D collaborative environment includes chat area and graphic area, where the graphic and chromatic aspects of the projects can be visualized and analyzed in group, synchronously or not. The *production axis* of the environment emphasizes the active and interactive participation of the learner. A sequence of problems is available, based on real cases, intending to integrate theory and practice of the contents used by architecture and design.

3.1 Contents, exercises and problems about color

Contents, exercises and problems related to graphic design are available in the learning nucleus of VLE-AD. Figure 2 shows the interfaces of this project. Ten interactive exercises about color theory and application are currently available. They emphasize aspects concerning analysis and execution of chromatic composition according to harmony and contrast principles, color parameters and color models. The students can do the exercises individually and send them to be evaluated at anytime.

The collection of contents is structured in a flexible and interactive way and can be accessed according to the learner's interests, not depending on time and place. The theoretical base is then grouped in five big axes: concept definition, classification, chromatic models, composition and color reproduction. In the first axis, *color concept* is defined based on its implications according to Physics, Physiology of Perception and culture. The item *chromatic models* deals with the characteristics and uses of the systems RGB, CMYK, HSB, HSV, CIE-LAB, Munsell System, and NCS. In the item *composition*, the principles of chromatic combinations, harmony strategies and contrast are explored. The item *color reproduction* approaches the reproduction systems, its particularities and applications. This item also deals with the apparent modifications that color experiences according to the formal context, environment and illumination. Each item also offers exercises, literature indications, study suggestions and tips that intend to amplify the basic knowledge about the topic. A specific color glossary is available along the whole learning environment. The learners also have access to an image bank, learning material, videos, animations, presentations, gallery of works developed by the groups, allowing the consultation at any time. They also can save their files, notes and projects in specific "places" on the server.

Figure2. Example of exercise interface of VLE-AD e interface of the Interactive Color Laboratory available in the environment. Source: http://ava.egr.usfc.br/ava/ad.

The problems are presented in scenes according to the complexity level and solved collaboratively. Starting at this initial scene, the students begin to explore the solving steps (problems definition, setting of student's goals, solving strategies, etc.) sending reports and receiving tutoring attendance. The analysis of the reports sent by the group allows the tutor to

evaluate the decisions, to indicate supportive material (texts, articles, abstracts, operational tips) that contributes to the solving process. All the structure to design graphic projects is available in the collaborative environment.

The problems in the color nucleus have been divided into categories according to their goals in three levels of complexity. Therefore, the level 1 problems involve activities related to description, identification, classification, comparison, analysis and conceptual synthesis. The level 2 problems involve activities related to adaptations, conversions, applications, specifications, analysis and applied synthesis. The level 3 problems are related to creation and proposition of graphic solutions.

The color-learning nucleus also provides the Interactive Color Laboratory (ICL) as a support to the exercises and problems solving. ILC (Figure 2) is a tool that allows the visualization, mixing and specification of colors in different models. It has three geometric basic structures that can exhibit chromatic combinations and background figures relations. ICL also presents an introductory text that approaches the aspects of color visualization in different devices.

4. CONCLUSIONS

At the current stage of the VLE-AD project, the "color-learning nucleus" is totally implemented. The pilot test of the environment is taking place based on the curse "Color in Graphic Design", in which contents, exercises and problems are being solved by students of the field.

After analyzing the results and validation of the model, we hope to create parameters to produce learning environments directed to knowledge fields based on graphic-visual language. We also intend to contribute in the improvement of quality of education and to attend the demand for continued education in the architecture and graphic design fields. It is believed that by creating accessing conditions not depending on time and place, and by encouraging group work we can promote solution of projects in a shared and distance process.

ACKNOWLEDGMENT

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A system of colors
dedicated to educational aspects of color

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ABSTRACT

Cecor® Color System is characterized for being directed towards education focusing the rather subjective questions regarding color. Inspired by other systems such as Ostwald, Munsell and Gerritsen's, Cecor was entirely computer developed within CMYK standard. Consolidated with its third version, Cecor can be specified in any notation system, for instance RGB, HSB, LAB, etc., when there is the need for standard colors. Cecor's flexibility allows adaptations to new demands as well as the edition of all its material in digital system. One of Cecor's most important aspects is its three integrated modules: 1) *Regular solid*, which describes the color characteristics in terms of Hue, Lightness and Saturation, allowing the digital edition of a multiple purpose color catalog with 2,421 samples. 2) *Didactic module*, which gives scientific and artistic support to the system, with 20 synthetic charts on theory and psychodynamic interactions in color. 3) *Harmony chart module*, formed by 22 basic harmonies that create more than 100,000 color matching plans. In practice, the system's chromatic basis can fully serve countless areas of final products, such as packaging, fabrics, coating and furniture, appliances, machines, vehicles and industrial equipment, paint and decorative accessories, etc. Cecor also includes an application of a refined chromatic methodology analyses for existing situations and prone to color renovation.

1. INTRODUCTION

Historically it can be affirmed that Cecor System began to be idealized circa 1994 more because of the lack of a "color culture". Even though Brazil is extremely rich in color, it was and still is very poor regarding the art and science of color. It was not a matter of reinventing the wheel since there had already been innumerable international systems in operation. The idea was to develop a system with a vocation in color didactics so as to spread this culture. Thus and with the use of computers came the idea of a system comprised of various modules, besides the descriptive system of colors, that also had other aggregated resources related to didactics, the harmonic processes and the meaning of colors so that with all the system digitalized, it could generate didactic material in several sizes and matters.

2. A GENUINELY BRAZILIAN COLOR SYSTEM

Inspired by notorious systems such as Ostwald's, Munsell's, the NCS and also influenced by Gerritsen (1973), Küppers (1973), Silvestrini and Fischer (1994), and Tornquist (1996) literature, Cecor System was possible to be developed only due to the computer. Thus Cecor is a thoroughly digitalized system.

The junction of two tetrahedrons in a three-dimensional structure forms its color space. The superior one has the colors of the *additive synthesis* (primary RGB) having in its vortex

the fusion of the two, which forms white. In the inferior are the colors of the *subtractive synthesis*, in whose vortex black is formed, also obtained by the fusion of the three colors of graphic process (primary CMYK).

The set has the HLS (Hue, Lightness and Saturation) axis that defines any color. The chromatic circle is located in the center (equator) like a pizza with 24 hues. Meanwhile each hue is unfolded into triangles with 100 color points forming the set with bright, vivid, neutral and dark shades in addition to the 21 achromatic points formed by the North-South central axis.

3. THE BENEFITS THAT CECOR SYSTEM PROVIDE

The benefits that Cecor is able to provide are also quite comprehensive. From the chromatic planning for auxiliary projects in architecture and decoration aimed at work, study or social surroundings to the development of courses, workshops and specific training for professionals, professors and color marketing executives.

In practice, the system's chromatic basis can fully serve countless areas of end products, such as packaging, fabrics, coating and furniture, appliances, machinery, vehicles and industrial equipment, paint and decorative accessories, etc. Cecor also includes an application of a refined chromatic methodology analysis for existing situations and others liable to color renovation.

4. THE FLEXIBILITY DIGITAL SYSTEM

Nowadays the CCS —Cecor® Color System— is characterized for being directed towards education focusing the rather subjective questions regarding color.

Consolidated with its third version (2001), Cecor can be specified in any notation system, for instance RGB, HSB, LAB, HSL, etc., when there is the need for standard colors. Cecor's flexibility allows adaptations to new demands as well as the edition of all its material in digital system. One of Cecor's most important aspects and its integrated three modules, as follows:
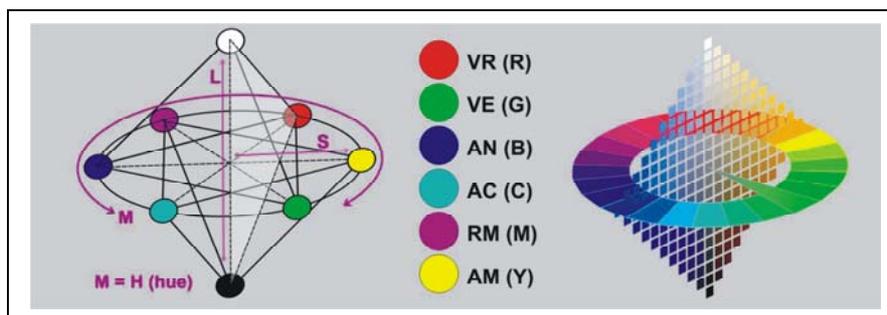
Figure 1. Color space: as in the system tree that describes the color characteristics in terms of Hue, Lightness and Saturation (HLS) allowing the digital edition of a multiple purpose color catalog with 2,421 samples. As Cecor is an open system, it can be enlarged to a greater number of colors.

Figure 2. Didactic module: gives scientific and artistic support to the system, with 20 synthetic charts on theory and psychodynamic interactions in color. Edited in various kinds of supports and sizes devoted to the study and teaching of the art and science of color.


Figure 3. Harmony chart module: formed by 22 basic harmonies that create more than 100,000 CMPs (Color Matching Plans). The charts are produced by customer order and work as coordinated color guidelines for any aesthetic or decorative purpose. This module derives from a basic product for the popularization of color culture (next figure).

Figure 4. The "harmony making and color mixing" disc that is sold cheaply at hardware and stationary stores.

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Imagination and color in the carioca scene

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ABSTRACT

This article is a result of the experiences made during the classes of "Fundamentals of Color", which I teach for the Fashion Design Bachelor Degree Course offered by the Faculty SENAI/CETIQT. We use the imaginative conception, based on Gaston Bachelard's principle of creative imagination for the conception of objects and places, as a methodology for teaching color to future designers. This didactic choice for the creative imagination was a result of a previous research done with the purpose of revealing the images built in the soul of the self when admiring an object or place. In this way the student self engross and wish to be in a place or to have an object, feeling he as a part of it (as if he has created it).

1. INTRODUCTION

The subject "Fundamentals of Color" is part of the curricula of the graduate course in design —with qualification in Fashion— offered by Faculty SENAI/CETIQT in Rio de Janeiro, Brazil. Considering the method to be used to teach color for fashion design, we assume that the coloring topic cannot be taken as a secondary issue in the development of the design project or only as a consequence of the rules for the application of balanced harmonies. Color is an inherent and structuring part of the object, and so the essence of it, that must be treat already in the conception of the project (Araújo 2003). All this reflection came from the research developed at the Pos-graduation Program of Architecture Faculty of the Federal University of Rio de Janeiro, where I have presented my Master thesis and where I am now doing my PhD research. The basic principle to make color something simple and fluent to the students of the design graduation course is to making use of the students' intrinsic imagination. It is a straight and, at the same time, complex conclusion when executed in the classroom.

As a result of my partial researches, it was developed an innovative method based on the creative imagination of Gaston Bachelard (1993) and on his poetic images approach. The support of Faculty SENAI/CETIQT was decisive for testing this pedagogic practice throughout the academic year of 2002-2003. During these years experiments in the classroom were done for testing the studies based both on Bachelard (1993) and Heidegger (2002) discussions of poetic images and creative imagination. The liberty within the simplicity of this thought has encourage the students and let them fascinated by the color subject, which contributed for not limiting themselves to the theory shown in the classroom, but to complement their research using books, articles and specialized periodicals. The imagination, and the images created by it, has built meanings during the conception process of the proposed project, and the color was treated by the students under an intuitive approach. The teacher posture in the classroom was outlined from the studies of Schön when he talks of the teacher as a leader of knowledge, not imposing ideas but promoting the debate and the reflection in the action.

Gaston Bachelard presents in his book *The poetics of space* the philosophic consideration that teaches us on how to comprehend the poetic phenomenon of a place from its poetics

images. The comprehension of these images is directly related with the liberty to imagine and constantly create objects and places, all of them filled with its colors, the colors of the creative imagination. The student produces new contexts to develop and to apply the color, so teach in the theory, by turning the day after day in something unexpected and by using conventions in a not traditional way (Venturi 1995). The exercise with images and color leads the group of students to meet their surrounding word and to capture details which ignored in the past, get now, within poetic power, a colored dimension. This alchemy ensures the image transformation letting the color to bring out spontaneously in the project. This impulsively creativity is part of the main structure of the photograph experiment suggested to the students of the "Fundamentals of Color" class for the conclusion of the course program.

2. METHODOLOGY

This imaginative exercise is developed from a colored photograph experiment, carried out in group with the purpose of making the detection of the images and of the color mixtures of the place a collective experience. The city of Rio de Janeiro was used as the theme, taking advantage of the personal history of each of the students on their day-to-day. The exercise was done both outside and inside the classroom, with the supervision of the teacher. This practice was based on the principles of action-reflection and on the encouragement of the frequently use of the imagination, here trained when visiting the registered place and when putting together the photograph experiment.

Photograph survey and creation of the color palette.

1. Photograph survey (outside exercise).
2. Experiment and composition of the photos, when the students work on the photo and on the visualized image using other elements, besides the photos, and give a meaning to the place (exercise done in the classroom) (Figure 1).
3. Creation of the palette with 20 colors, concept from the experiment and composition exercise that at this moment includes the colors developed by the group (exercise done in the classroom) (Figure 2).

Figure 1.
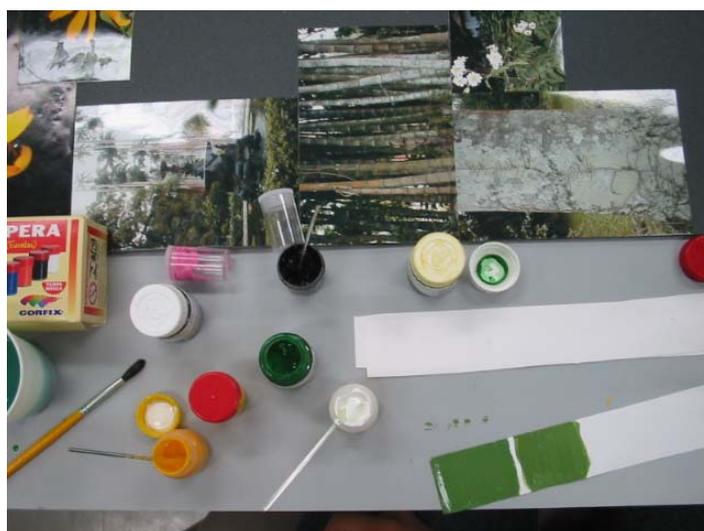
Figure 2.

The theme of Rio de Janeiro was divided in five groups:

1. *Boehm Rio*: places to meet friends, musicians and poets. Traditional bars and restaurants of the city.
2. *Cultural Rio*: places where artistic manifests are performed and where the carioca change information and ideas.
3. *Tourist Rio*: places where the carioca hosts and show his beauty.
4. *Natural Rio*: places where the city is exuberant.
5. *Historic Rio*: places from where the city was found.

The practice in the classroom both to compose the photographs panels and to create the colors was always based in the conceptive thought. A magic and poetic world was then created, where the student was usually invited to fancy and to outline new and different proposals.

3. THE RESULT

When observing the result of this deep creative practice it can be note a coloring thought blowing up into forms and colors that translate the *genius loci*[1] of the different types of Rio de Janeiro (Figures 3 and 4). This searching for color aroused in the group the pleasure of executing and coloring. The students demonstrated familiarity with the coloring issue through their works, and discovered that it is part of their lives. The pedagogic results have also migrated to other classes of the design course. This confirmed the penetration of the theoretical knowledge of color when it is taught using a gamely practice where the act of working come to be a pleasure. The results achieved fully completed the objectives of the class.

Color turned to be an element of mind, considering that the imaginative creation, which concepts the project, have a subjectively manifested in the object only through the imaginative conception. This attitude of natural color is important for the future designer since color is no more a decorative element and it becomes structure of the projected object. With this idea the designer gets involved with the object and with who is going to use it. The gamely experience in the classroom during the designer education make possible the development the spontaneity of his expression, which gives identity to the project. It is in this sense that each created object is unique and consequently innovative, as far as it is originated by an insight from a creative imagination that results in an imaginative conception, that is, in an imaginative action. Analyzing the results of the exercise developed from the conceptive method of the creative imagination, it can be verified images and colors that result from the arrangement between pleasure and work. "We breathe obsession, obsessions of happiness" (Bachelard 1993: 25). This evocation concerns to each individual, and particularly to the designer that outlines the object.

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[1] The atmosphere (essence) of the place that grants personality and life to it.

Figure 3.

Figure 4.

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Analysis of colour effect in Japan - South Korea World Cup football game

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ABSTRACT

The video images of the FIFA Japan-South Korea World Cup 2002 were used to investigate the effect of coloured team shirts on spectators for viewing football matches.

1. INTRODUCTION

Colours could have an impact on spectators when watch a sport competition on TV. In this study, the colours of team shirts affecting spectators were investigated. The video images of the 24 games in the FIFA Japan-South Korea World Cup 2002 were used. Fifty subjects participated in the experiment to scale the impression and discrimination of the colours of both teams in each game using a semantic differential method. The results are reported here.

2. EXPERIMENTAL

The 24 games in the 2002 FIFA Japan-South Korea World Cup were recorded by a video recorder. For each game, the two teams played together with the colours of team shirts are summarised in Table 1. There were many parameters could affect the spectators' judgements such as time, venue, weather, temperature, lighting condition, angle of TV camera. It was considered to be necessary to unify the way to sample the video image in each game. The final decision was made to use one minute video image to represent a game, which was taken during the 15th to 16th minute from the start of a game. The goal scene and sound were discarded since these parameters could affect each subject's judgment in the experiment.

Subjects simultaneously judged the effect of uniform colours of the two teams in a match using twelve semantic differential scales, for which each scale was defined in terms of a word pair. These scales are plain-gaudy, fresh-not fresh, vivid-dull, fast-slow, not clear-clear, dirty-beautiful, heavy-light, distinguish-undistinguish, light-dark, cool-hot, strong-weak, stylish-not stylish. These scales were determined by conducting questionnaire within a group of 196 people over a period of 2 months.

In the experiment, each subject was asked to assign a number from 1 to 7 for each scale. For example, the 7 categories for the vivid-dull scale are: -3: extremely dull, -2: quite dull, -1: slightly dull, 0: neither vivid nor dull, 1: slightly vivid, 2: quite vivid, and 3: extremely vivid.

In the experiment, subjects sit in front of a CRT display with a distance of 1.5 meter. The experiment was divided into 12 sessions. In each session, two to five subjects performed the experiment at the same time to judge xx games. For each game, video image was played for 1 minute, and each subject reported the results for all 12 scales. A total of 50 Japanese students, 35 males and 15 females, participated in the experiment. Their ages ranged from 18 to 26 years old with an average of 22 years.

Table1. Combination of the uniform of an image sample used for the experiment.

1.Senegal (H: white, green) – France (H: blue, white)	2. Uruguay (H: light blue, black) – Denmark (H: red, white)
3.France (A: white) – Uruguay (H: light blue, black)	4. Denmark (H: red) – Senegal (H: white)
5.Denmark (H: red, white) – France (A: white, blue)	6. Senegal (A: green) – Uruguay (H: light blue, black)
7.Paraguay (H: red, blue, white) – South Africa (H: white)	8. Spain (H: red - dark blue) – Slovenia (H: white, green)
9.Spain (H: red, dark blue) – Paraguay (A: orange, white)	10. South Africa (H: white) – Slovenia (A: green)
11.South Africa (A: yellow, green) – Spain (H: red, dark blue)	12. Slovenia (H: white, green) – Paraguay (H: red, blue, white)
13.Brazil (H: yellow, blue) – Turkey (H: red)	14. China (H: white) – Costa Rica (H: red, blue)
15.Brazil (H: yellow - blue) – China (A: red)	16. Costa Rica (H: red, blue) – Turkey (A: white)
17.Costa Rica (H: red, blue) – Brazil (H: yellow, white)	18. Turkey (H: red) – China (H: white)
19.Korea (H: red, dark blue) – Poland (H: white, red)	20. USA (H: white, blue) – Portugal (H: brown, green)
21.Korea (H: red, dark blue) – USA (H: white)	22. Portugal (H: brown, green) – Poland (H: white, red)
23.Portugal (H: brown, green) – Korea (A: white, red)	24. Poland (H: white, red) – USA (A: blue, white)

Note: Each game gives the name of a country (Home or Away: The main colours on the team shirt).

The semantic differential method was then used to analyse the visual results. Although the experiment was conducted using Japanese language, the experimental results presented here are in English. There could have some discrepancies between the two languages due to the culture difference.

3. RESULTS

The raw data in terms of 1 to 7 points for each scale were averaged for all the games to represent each subject's score. These data were given in Figure 1 for each word pair. For a perfect agreement between individual results indicating no colour effect, all points should be overlapped with each other. A large spread of data indicates shirt colours affecting spectators' judgements.

Detailed analysis shows that the scales affected by colours are distinguishable-undisguishable, clear-not clear, vivid-dull and gaudy-plain. On the other hand, fast-slow, dirty-beautiful, strong-weak, stylish-not stylish are not affected much by colour. There are two scales largely affected by colour: distinguish-undistinguish and clear-not clear. A student *t* test was carried out to test whether these scales have no significantly effect by the colours of uniforms. The results confirmed the finding because their *t* values are exceeding the 95% critical values.

The factor analysis was also carried out and the results showed that the 12 scales investigated are categorised into three groups (see Table 2). These are factor 1 associated with mainly fresh-stale including light-heavy, fresh-stale, beautiful-ugly, light-dark, fast-slow, cool-hot; factor 2 associated with discrimination including gaudy-plain, vivid-dull, clear-not clear, distinguishable-undistinguishable, weak-strong; and factor 3 associated with stylish-not stylish.

Figure 2 shows the scores of all 24 games for the two scales having statistically significant effect by shirt colours: undistinguish-distinguish and not clear-clear. It can be seen that there are large spreads of the data for both scales and the scores for games 8, 11, 13, 14, 15, 16, 18 and 21 having higher values. The scores of the 24 games are also plotted in factors 1 and 2 diagram, and factors 3 and 1 diagram in Figure 3. It can be found that these games had higher scores in factor 2 associated with colour discrimination.
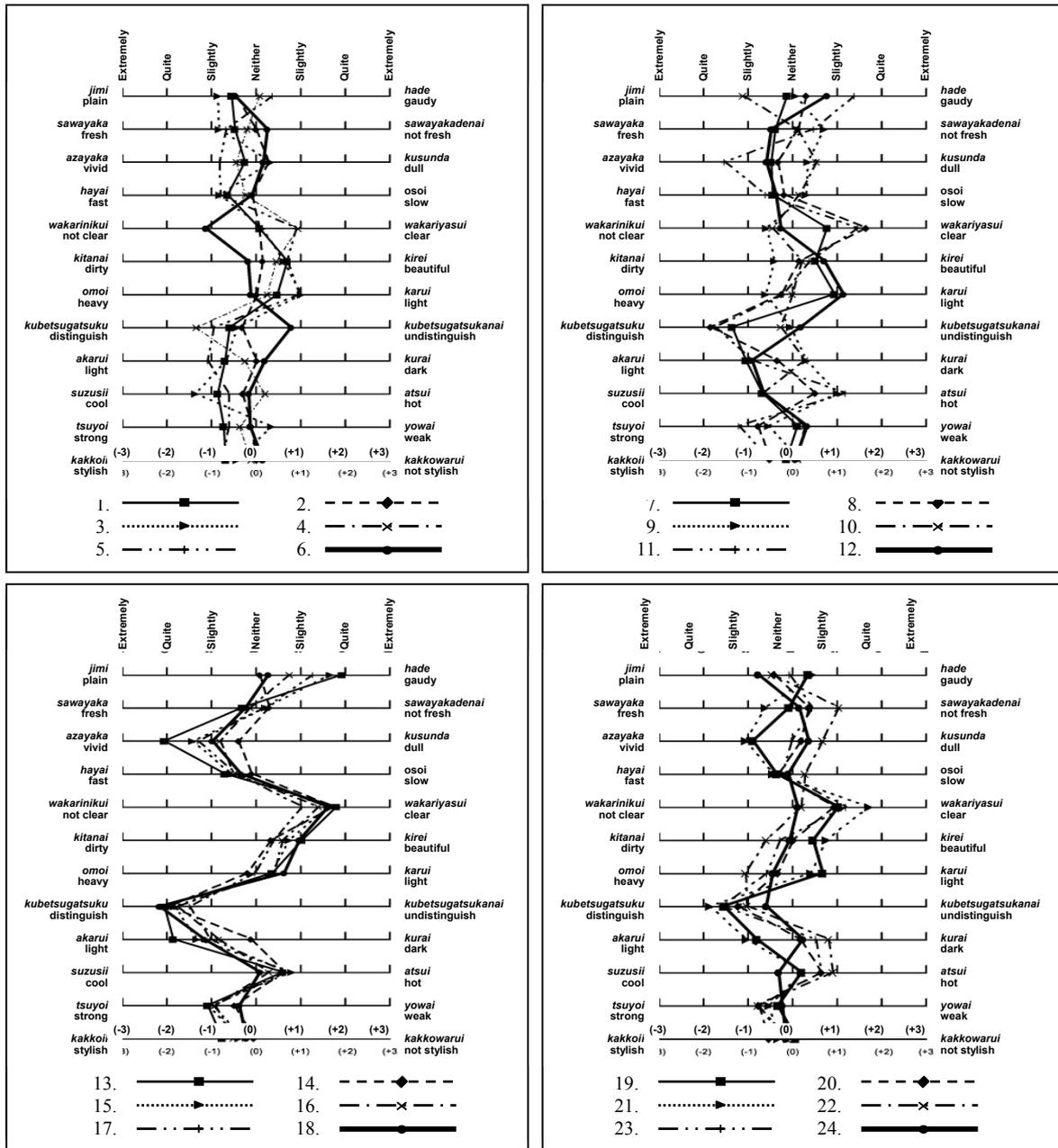
Figure 1. SD profile (the number shows the combination of the uniform of Table 1).


undistinguish-distinguish
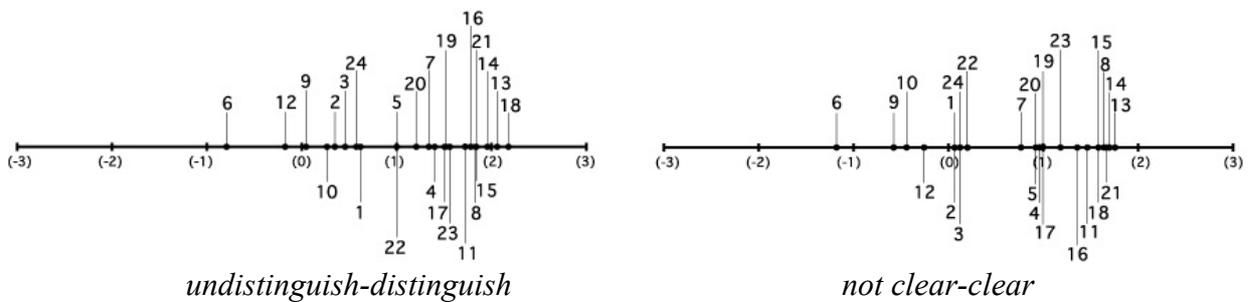
not clear-clear

*Figure 2. Each game's score in undistinguish-distinguish and not clear-clear scales.*
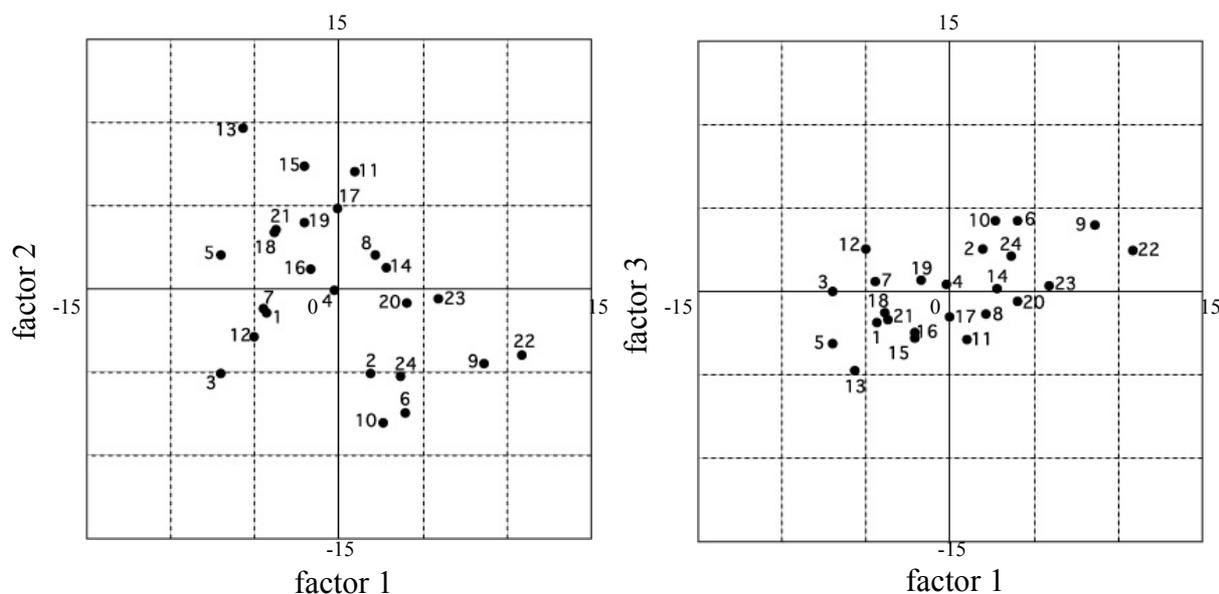
Figure 3. The factor score for each game in factors 1 and 2 diagram, and factor 3 and 1 diagram.

Table 2. The amount of factor loads.

SD word pair	factor 1	factor 2	factor 3
omoi / heavy – light / *karui*	-0.9709	0.0255	0.0537
sawayaka / fresh – not fresh / *sawayakadenai*	0.9423	0.1091	0.1550
kitanai / dirty – beautiful / *kirei*	-0.8574	0.4003	-0.1573
akarui / light – dark / *kurai*	0.7546	-0.6047	0.1475
hayai / fast – slow / *osoi*	0.7305	-0.2945	0.4889
suzusii / cool – hot / *atsui*	0.7167	0.6933	-0.0041
jimi / plain – gaudy / *hade*	-0.1562	0.8898	-0.0640
azayaka / vivid – dull / *kusunda*	0.4180	-0.8847	0.1240
wakarinikui / not clear – clear / *wakariyasui*	-0.0963	0.7452	-0.3857
kubetsugatsuku / distinguishable – undistinguishable / *kubetsugatsukanai*	0.0228	-0.7211	0.3576
suyoi / strong – weak / *yowai*	-0.3721	-0.6870	0.5184
Kakkoii / stylish – not stylish / *kakkowarui*	0.2959	-0.3028	0.8728
The rate of contribution (%)	38.48	35.99	13.66
The rate of accumulation contribution (%)	38.48	74.47	88.13

4. CONCLUSION

In this experiment, 50 subjects judged 24 games of video images using 12 semantic differential scales. The results from the factor analysis showed that all scales can be grouped into three associated with colour discrimination, fresh-stale and stylish-not stylish. There are two scales affected by colours: undistinguish-distinguish and not clear-clear.

We will continue to accumulate experimental data based on the judgements of two team's shirt colours in order to establish more comprehensive results. We will also investigate the individual shirt colour in a game. This is the only way to relate individual colour with spectators' emotion. This can also show individual colour affected by the opponent colours.

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Emotion induced from colour and its language expression

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ABSTRACT

In order to develop the colour system corresponded to human colour emotion, words imaged from colours were collected in Japan and Thailand. The words were compared with adjectives used in colour systems.

1. INTRODUCTION

Colour can be described through some systematic methods such as colour system, colour name, and colorimetric values. The attributes of a colour system, colour names and colorimetric values are related to some of human colour emotion in many cases. English colour emotion words are used as a bridge between them. As there are usually some differences between sensations and their expressions in two language areas, it is important to investigate whether the English expression are suitable for the expression of colour emotion in the outside of English language area. The aim of this study is to know the relationship between adjectives used in colour systems and colour emotion words used in the outside of English language area. We collected colour emotion words imaged from colours in Japan and Thailand, and compared the collected words with adjectives used in colour systems.

2. METHODOLOGY

In our previous studies (Nakamura et al. 1994, Pungrassamee et al. 2002), we collected many adjective words expressing colour emotion through a dictionary, and we discussed the relationship between the words and the location in Munsell colour space. We also numerically expressed some colour emotions as formulae with using CIELAB colorimetric values (Sato et al. 2000). In this study, we investigated the relationship between adjectives used in colour systems and colour emotion words used in the outside of English language area. Specifically, we asked observers to choose the word corresponding to an emotion induced from a colour.

2.1 Colour sample

A set of dyed polyester colour samples, selected from the SCODTDIC PLUS 2000 polyester system manufactured by Kensaikan Co. Ltd, were used to carry out visual assessment. The samples were rectangular (1.5 cm × 1.2 cm) and colours were chosen from all over colour space. Only one colour sample was chosen from a colour tone area through a hue-tone dividing method (Teraji 1991, Sato and Teraji 1989, Sato and Nakamura 1999) that allowed colour space to be split along the lines of appearance attributes. The number of the colour samples was 212.

2.2 Visual assessment

In order to know the relationship between a colour emotion word and a real colour, a visual assessment was carried out in both of Japan and Thailand. It was to choose emotional words induced from sample colours. The emotion words used in this study have been gathered in previous studies (Nakamura et al. 1994, Pungrassamee et al. 2002) already. The numbers of the words gathered in Japan and Thailand were 151 and 69, respectively. The visual assessments were carried out under a north-facing window in Japan and under D65 light condition with a viewing cabinet in Thailand. Each sample was covered with a light grey surround to provide uniform surround viewing conditions. 43 Japanese female students were asked to choose only one emotion word. 30 Thai observers, who use colours such as dressmakers, graphic designers and architectures, were asked to choose plural emotion words.

No	Tone	No	Tone
1	pale greyish	8	bright
2	pale	9	dark greyish
3	light greyish	10	dark
4	light moderate	11	deep
5	light	12	strong
6	greyish	13	vivid
7	moderate		
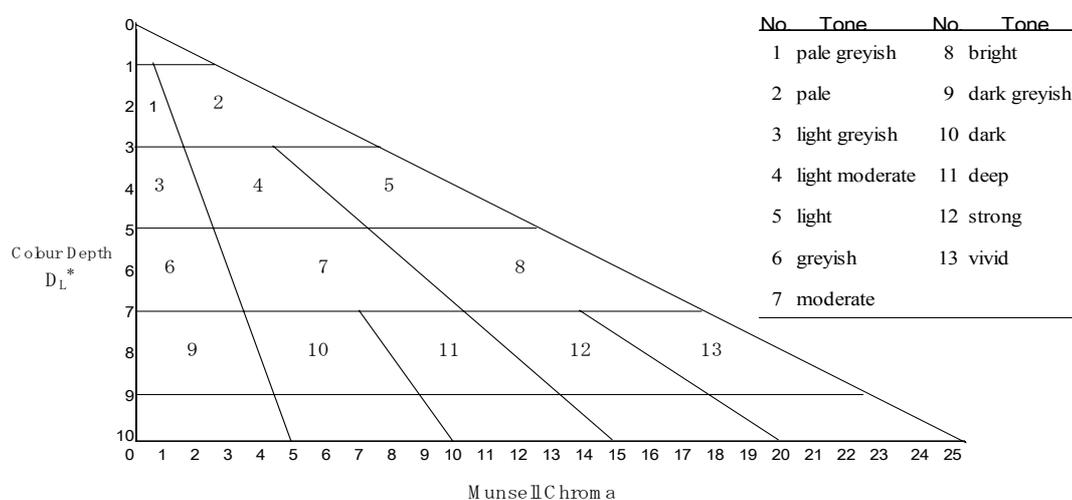
Figure 1. Colour tone system used for sampling in this study.

Table 1. Adjectives used in Japanese Industrial Standards JIS Z 8102.

Japanese	English	Symbol
azayaka-na	vivid	vv
akarui	light	lt
tsuyoi	strong	st
koi	deep	dp
awai	pale	pl
yawarakai	soft	sf
kusunda	dull	dl
kurai	dark	dk
goku usui	very pale	vp
akarui haimi-no	light greyish	lg
haimi-no	greyish	mg
kurai haimi-no	dark greyish	dg
goku kurai	very dark	vd
chui-no	medium	md

Table 2. High frequency emotion words chosen by Japanese observers.

Japanese	English	Frequency
Jimi-na	plain	263
ochitsuita	calm	224
shikku-na	chic	175
awai	pale	144
kofu-na	antiquated	138
eraganto-na	elegant	120
kuria-na	clear	108
azayaka-na	vivid	105
omoomoshii	grave	100

Table 3. Colour emotion words chosen by Thai observers: Sum on every hue.

Hue	Number of sample	Kind of word	Number of overlap	Highest overlapped word
5R	12	15	2	
10R	12	14	3	*swang* / light
5YR	12	12	2	
10YR	10	12	2	
5Y	10	14	2	
10Y	10	15	2	
5GY	12	18	4	*swang* / light, *sai* / clear
10GY	9	14	2	
5G	9	13	3	*tube* / turbid
10G	9	14	2	
5BG	9	11	3	*khem* / deep
10BG	8	15	2	
5B	8	19	3	*klam* / dark, *tuem* / dim
10B	10	16	2	
5PB	12	13	2	
10PB	12	17	3	*nual* / creamy
5P	12	15	3	*sod* / fresh, *khem* / deep, *tube* / turbid
10P	12	17	3	*khem* / deep
5RP	12	16	4	*sai* / clear
10RP	12	22	3	*sod* / fresh
per sample	--	1.42	0.25	

Table 4. Colour emotion words chosen by Thai observers: Sum on every tone.

Tone	Number of sample	Kind of word	Number of overlap	Highest overlapped word
pale greyish	20	16	12	*bow* / light
pale	20	14	9	*nual* / creamy, *swang* / light
light greyish	20	7	6	*mou* / dusky, *mon* / sombre
light moderate	20	11	3	*nual* / creamy
light	14	10	12	*sai* / clear
greyish	20	12	15	*tube* / turbid
moderate	20	10	7	*khem* / deep
bright	14	12	11	*sod* / fresh
dark greyish	20	14	18	*mued* / dark, *tube* / turbid
dark	20	16	9	*khem* / deep
deep	14	7	5	*khem* / deep
strong	10	11	8	*sod* / fresh
per sample	--	0.66	0.54	

3. RESULTS AND DISCUSSION

Table 1 shows all of adjectives added to basic hue names on Japanese Industrial Standards JIS Z 8102. The kind of the adjectives is 14, and they are 9 kinds if "greyish" and "very" are not counted. Table 2 shows high frequency emotion words more than 100 times chosen by Japanese observers in the visual assessment. The highest frequency word was "*jimina* / plain". The frequency was 263 and it corresponds to 2.89% of the whole answers. The kind of the words chosen more than 100 times was 9. Only two words, "*awai* / pale" and "*azayaka-na* / vivid" are the same to the word used in JIS Z 8102. This means that Japanese usage of colour emotion words is not the same to the category of the systematic colour system defined in JIS. Moreover, it may differ from usage of the language in the English language area.

Tables 3 and 4 show the kind of colour emotion words chosen by more than half of Thai observers on every hue and tone categories. And the numbers of the overlaps and highest overlapped words are also shown in the tables. The numbers of overlap per sample on hue and tone categories are 0.25 and 0.54, respectively. This means that some emotion words chosen by Thai observers are related to the tone categorising of the colour sample more than the hue. Table 3 shows that differences among the kind of words and number of overlaps on every hue are about the same. Table 4 shows that differences among the kind of words and number of overlaps on every tone are lager than those on hue shown is Table 3. This means that some Thai words imaged from colours are related to colour property of each tone category. It seems that the emotion words in Thai are affected by the tone although a difference is between the characteristics.

With the comparison between Japanese and Thai results, we found that the usage of colour emotion words and their characteristic change with languages. Therefore, when examining the colour emotion and linguistic expression which are received from a systematic expression of a colour, and a colour among other languages, it has suggested that it needs to be cautious of the expression characteristic. We also found that we do not need only adjectives used in colour tone and name systems but also other emotion words. This has suggested a new systematic expression, in order to express more faithfully the sensation induced from colour.

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CLOSING SESSION

Closing ceremony speech from AIC President

Paula J. ALESSI
Eastman Kodak Company

To my esteemed AIC friends and colleagues and to the organizers and members of the Brazilian Color Association, it is my distinct honor and pleasure to present a short closing speech. I would like to summarize the journey we have been on together for the last three days. Let's see what we have learned by looking through the Color and Paint lens that lit our way on our color journey in Porto Alegre together. First we were enlightened on the concept of fluorence by Osvaldo da Pos. Then in our session on color perception, we heard a new theory from Jesús Zoido and his Spain colleagues, a color naming method to evaluate the impression of colored patterns from Shoji Sunaga, how some hues are remembered more easily than others from Helen Epps and how color ratings for safety signs change between young and elderly people from Haruyo Ohno. In the ECD architecture section, we learned about a structuralism system for an office complex from Mari Ferring, how color and light interact in architectural designs from María de Mattiello, about Paul Scheerbart's utopia of colored glass from Gertud Olsson and about Le Corbusier's color keyboard arranged as the keys on a piano from Verena Schindler. In the section on architecture and landscape, we heard Vojko Pogacar talking about his twelve-period seasonal color typology based upon astronomical and geometrical correlations, Michel Cler's paper on color globalization (which was presented by Verena Schindler), and Richard Kjellström on the local colors and the identity of a region. In the color emotion section, we learned about the different emotions evoked by looking at small chips as opposed to viewing the same colors in rooms from Beata Stahre, about the associations people make regarding different colors from Helen Epps on behalf of Naz Kaya and about how it is difficult to relate color combination sensations to colorimetry in a linear way from Aran Hansuebsai on behalf of Suchitra Sueeprasan.

On the second day, during the colored space and design section, we learned from Luciano Guimarães about using color as information with positive and negative actions to form a model for the analysis of color. Monica Billger shared with us how first year architecture students use models, props, paint and lighting to build colored rooms that evoke many different kinds of responses and feelings. Next Maud Hårleman gave us insight on the positive and negative emotions that different colors can evoke in full-scale rooms facing north and south. Then Karin Fridell Anter shared the role of painted surfaces in architecture. The example that impressed me the most was the one dimensional stucco relief that was created to give the illusion of texture and depth.

In the session on color education, Garth Lewis gave us an impressive live demonstration of how a gradient tool on a computer monitor can be used as a mixing tool to teach students about simultaneous contrast and color mixing as it relates to paints. Renata Pompas shared color teaching plans for Italy on behalf of herself and her co-author, Lia Luzzatto, with a very lively and entertaining video to the end the presentation.

Next, we had the pleasure of hearing an invited lecture given by Mônica Araújo, on behalf of Robert Hirschler, discussing how attending the SENAI/CETIQT Color Institute in Rio de Janeiro provides the student with a learning experience through engaged actions rather than a teaching experience of listening to lecture after lecture.

In the aesthetics and harmony section, Claudia Stern gave us food for thought on how color in sculpture just happens naturally, not necessarily intentionally. Nelson Bavaresco shared his harmonic composition scale consisting of 24 complementary colors according to their

lightness. Next Helen Gurura shared her research on using colors found in supermarket packaging in a study on the importance of background color when interpreting the appearance of the foreground color.

In the section on color order systems and paints, Kristina Holmberg explained how the NCS system has evolved to the 1,950 samples represented in 2004 and how the system is used widely in the paint industry. Berit Bergström shared many fascinating aspects of color communication between different paint materials and surfaces like gloss and matte. Professor José Caivano provided us with more insight into the concept of cesia as it relates to a new atlas of paint samples that he has been working on in conjunction with Sherwin Williams.

Finally, the last day ended with a delightful invited lecture from Daniel Lozano on the practical aspects of appearance in paints that are known to us all but we usually never take the time to formulate a complete understanding of these aspects and all their implications. He also gave us an appreciation for the fact that not everything we see can be accurately measured.

In the session on appearance and color difference, Dr. Ronnie Luo gave a talk on behalf of his two graduate students Ho, Cui and colleague, Rigg, telling us that color difference formulae like BFD, CMC and CIEDE2000 all perform well in their correlation to visual results for color differences from small ΔE^*_{ab} values of 5 to large ΔE^*_{ab} values greater than 10. Next Dr. Duangmal talked about color appearance of fruit juice containing vitamin C. We learned that adding vitamin C degrades the anthocyanin pigment, but it increases nutritional value and observers could not visually detect the color differences in the juice over time. We ended this session with Dr. Ronnie Luo giving us a very lively invited lecture on CIEDE2000. We learned that CIEDE2000 was designed to solve the imperfections of the 1976 CIELAB color difference formulae. We also learned how to apply measurement data and visual data to define the tolerances for our own particular applications. Another important learning was that we should use CIEDE2000 for blue colors, even though CIEDE2000 and CMC also perform similarly in many cases.

Our final session was on colorimetry and textiles. Ana Marija Grancarić shared with us the use of UPF (ultraviolet protection factor) as a means of classifying cotton fabrics based on their ability to protect the skin from the radiation of the sun. It was interesting to find out that as the concentration of optical brighteners increases, so does fluorescence, but whiteness decreases. Next Martina Viková showed how photochromic textile samples can be used as sensors for UV radiation. Jennifer Gay taught us that UV calibration is necessary before you measure whiteness and instrumental whiteness evaluation is still better than visual evaluation, although some improvements need to be made in instrumental whiteness measurement. Jennifer's experiments showed that the portable instrument performs compatibly with bench-top instruments. Michal Vik presented a nice survey of various color difference formulae, from CIELAB developed in 1976 to CIEDE2000. Then he shared his laboratory results on many observations for textile color centers showing the performance of all these color difference equations using the PF/4 metric and the percent discrimination metric.

To close our conference, an invited lecture by Dr. Allan Rodrigues enlightened us on color technology and paint, with a concentration on automotive aspects. We saw wonderful demonstrations of video color styling for cars. He made us familiar with the importance of being able to measure gonioapparent color. Allan did an outstanding job of making us familiar with all the aspects of color and automotive paints that are successfully used today in the cars that we all drive.

Now it is time to express heartfelt thanks. First to the organizers and members of the Brazilian Color Association: Thank you so much for arranging the venue, for getting Fellini Turismo to help with our hotel arrangements and tours. Thank you to Office Marketing for registration and audiovisual assistance. Thank you to Professor Hanns-Peter Struck for his many hours of blood, sweat and tears in preparing the meeting. Thank you to Professor José

Caivano for completely arranging all aspects of the technical program. Thank you to NCS for sponsoring that wonderful Brazilian dinner and entertainment Thursday evening. Thank you to all speakers and poster paper presenters for enlightening us on new aspects of color.

Now lastly, it is time to say good-bye. I really don't like to even say good-bye. So let's say "until we meet again", hopefully at the AIC 10th Congress in Granada, Spain. As AIC President, I declare this AIC 2004 Interim Meeting on Color and Paints in Porto Alegre, Brazil officially closed. I wish everyone a safe journey home!

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Next AIC Congresses

AIC Color 2005, May 8-13, 2005, Palacio de Congresos, Granada, Spain
Chairman: Javier Romero
Web: www.ugr.es/~aic05/

AIC Color 2009, September 20-25, 2009, Luna Park, Sydney, Australia
Chairman: Nick Harkness
Web: www.aic2009.org

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