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ACHROMATIC HUES MATCHING IN GRAPHIC PRINTING

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Sažetak

U industrijskoj praksi, tehnolozi, dizajneri i grafičari, svakodnevno se susreću sa zadacima precizne reprodukcije boje i usklađivanja tonova. Cilj je postići obojenje s definiranim parametrima boje i remisijskim svojstvima što bližima zadanom standardu. Tehnološki napredak u nekoliko posljednjih dekada uvjetovao je porast zahtjeva na kvalitetu reprodukcije i usklađenosti boje, dok se od same proizvodnje zahtjeva kraći i jeftiniji proizvodni proces. U takvim uvjetima, reprodukcija boje općenito, a posebno akromatskih tonova postaje vrlo kompleksan proces, obzirom na postavljene zahtjeve i brojne čimbenike koji utječu na reprodukciju u akromatskom području. U ovom radu analizirani su crni i tamno sivi akromatski tonovi s prosječnom vrijednošću svjetline $L^* \leq 20$. Provedeno je subjektivno i objektivno vrednovanje boje, te je prikazana usporedba rezultata razlika u boji dobivenih objektivnim vrednovanjem putem dvaju formula: CIELAB i CMC(l:c).

Ključne riječi:

akromatski tonovi, vizualna percepcija, objektivno vrednovanje, prostor boje, CIELAB, CMC(l:c)

Abstract

Some problems in process of dark achromatic hues reproduction and matching in graphic industry, where requests on colour matching are very high, are discussed. When achromatic hues is concerned, in terms of high requests on colour parameter matching, right on time production, quick response and high quality standards requests, the production and moreover the reproduction is subject to many variables and represent the manufacturing process of high complexity. The aim is to achieve a graphic reproduction with defined colour parameters and remission characteristics as close as possible to a standard. In this paper, black and grey hues characterized with average lightness value $L^* \leq 20$, were analysed. Subjective as well as objective colour evaluation have been performed and results of colour differences obtained by two colour difference formulae, CIELAB and CMC(l:c) have been compared.

Key words:

achromatic hues, visual perception, objective evaluation, colour space, CIELAB, CMC(l:c)

1 Introduction

In practice the colour matching, in general, is performed based on objective instrumental evaluation of colour parameters and their differences using CIELAB colorimetric system, according to tolerances set by ISO standard. The problem that the scale of CIELAB formula is not in accordance to visual perception of colour and their differences, and this is more emphasized in the area of achromatic dark hues where objective evaluation cannot obtained the difference values in accordance to psychological experience of colour. By the transformations of CIELAB formula, the new formula which are in better agreement with the average observer, has been developed (CMC(l:c), CIE94, CIEDE2000). The practice has proved the CMC (l:c) formula to be in one of the best correlations with visual perception of colour difference [1-10].

As it comes to evaluation of blackness the visual assessment, although it cannot be completely standardized even with established guidelines for viewing conditions, should not be underestimated. The blackness and the sensation of achromatic in general is, finally, a matter of subjective perception and, as it stands in literature [1-6], this can only be assessed visually or by measurement that can be correlated with visual assessment. In this paper

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2 Method

2.1 Samples Selection

The analyses were performed on a set of 20 samples printed in achromatic hues.

2.2 Objective Analyses

Objective evaluation of samples were performed by means of spectrophotometric measurement performed by remission spectrophotometer DataColor® SF600+CT (measurement area = 2,6 cm; measurement geometry d/8°). The measurement has been performed in aim of numerical evaluation of a*/b* colour coordinates as well as L*, C*, h* colour parameters. The measurement results are showed in Table 1 and graphically in a*/b* colour space (Figure 1). Based on results obtained, the sample 11 (values a*/b*<±1 i L*< 16) has been selected as referent sample for further procedure of visual assessment as well as objective colour difference evaluation.

In a following work the analyses of colour differences calculated according to CIELAB (1) and CMC(l:c) (2-5) formula. Total colour difference values has been defined (ΔE) and differences in single colour parameters (ΔL*, ΔC*, Δh*). Also, two different formula have been compared [1-6].

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

$$\Delta E = \sqrt{\left(\frac{\Delta L^*}{l \cdot S_L}\right)^2 + \left(\frac{\Delta C^*}{c \cdot S_C}\right)^2 + \left(\frac{\Delta H^*}{S_H}\right)^2} \quad \text{where: } (2)$$

$$S_L = \begin{cases} 0{,}511 & \text{if } L_s^* < 16 \\ \dfrac{0{,}040975 \cdot L_s^*}{1 + 0{,}01765 \cdot L_s^*} & L_s^* \geq 16 \end{cases} \quad (3)$$

$$S_C = \frac{0{,}0638 \cdot C_s^*}{1 + 0{,}0131 \cdot C_s^*} + 0{,}638 \quad (4)$$

$$S_H = S_C \cdot (T \cdot f + 1 - f) \quad (5)$$

2.3 Subjective Analyses

The subjective analyses was set based on visual evaluation by 20 normal colour vision observers. The observers were asked to rank all tested samples by assigning the value 1 to the reference sample being the most achromatic and the value 20 to the sample being least achromatic and being observed with reddish, bluish, or greenish sub - hue. The results of ranking based on visual assessment are shown in Table 1 and graphically in compare to objective values of lightness L* and chroma C* on Figure 1.

3 Results and Discussion

As the term of achromatic is referred to a very narrow area in the colour space, close to a vertical co – ordinate of lightness with a*/b* co-ordinates set close to centre. Only the samples set within the a*/b* values of ±1, which assure the minimal C* value, can be defined as placed in near achromatic area. In theory, in such setting of colour parameters the human eye should be able to perceive purely achromatic colours, and if the lightness parameter is L* < 16, purely achromatic black would be perceived. Samples with the same a*/b* settings and minimal C* value but with higher lightness L* (17 – 20), will be perceived as achromatic grey. But, if the slightest movement in a*/b* coordinates occur, the change of chroma C* parameter will move the achromatic nature of the hue towards chromatic – achromatic. Those areas will no longer be perceived as black or greys but will be perceived in certain chromatic hue – bluish, greenish, reddish, etc. In such case the achromatic hues matching will be problematic [1-10].

Based on spectrophotometric measurement, the objective values of colour parameters (L*,a*,b*, C*, h*), for tested samples were obtained and shown in Table 1. Based on a*/b* coordinates the placement of samples in a*/b* colour space is shown on Figure 1.

Based on a*/b* values and position of measured samples in a*/b* space, the level of chroma can be defined.

For samples 1, 11, 15, 16, 17 and 20, measured values of a*/b* coordinates are in a*/b* ≤ ± 1 values, which satisfy the request of minimal chroma. Based on such objective values, the samples mentioned can be defined as achromatic. The deficiency of a*/b* diagram is inability of lightness level definition, which is the most important parameter in the achromatic area, according to which the achromatic colour will be defined as white, grey or black. The samples with optimal lightness values L*< 16, will be perceived as black while the samples with higher lightness value will be perceived as scale of greys. Based on lightness values L*, the samples mentioned (1, 11, 15, 16, 17 and 20), are satisfying the requirement of lightness value, except the sample 17 which has the lightness value L*=17,6.

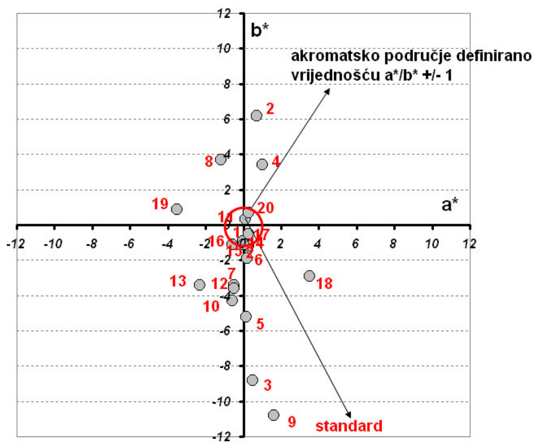

Figure 1. a/b* diagram of tested samples*

Table 1. Measured values of colour coordinates and parameters in compare to visual ranking

OBJECTIVE EVALUATION																				
	Samples																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
L*	16,4	16,8	20,3	19,6	18,4	13,9	17,6	12,6	18,7	17,5	13,5	16,8	16,9	14,3	16,5	16,6	17,6	16,4	13,1	15,5
a*	-0,02	0,7	0,5	1	0,16	0,2	-0,5	-1,2	1,6	-0,6	0,1	-0,5	-2,3	0,3	0,01	-0,6	0,3	3,5	-3,5	0,3
b*	-0,9	6,2	-8,8	3,4	-5,2	-1,9	-3,4	3,7	-10,8	-4,3	0,3	-3,6	-3,4	-1,2	-1,1	-1,1	-0,5	-2,9	0,9	0,7
C*	1,01	6,2	8,8	3,5	5,3	1,9	3,4	3,8	10,9	4,4	0,3	3,6	3,5	1,3	1,1	1,1	0,6	2,9	1,2	0,8
h*	269,9	275	269,9	73,6	271,7	272,5	262,1	108,6	278,6	261,5	71,6	262,5	255,9	281,8	270,41	269,9	300,7	267,78	131,6	66,8
VISUAL ASSESMENT																				
	Samples																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Ranking	5	15	20	18	16	6	11	7	19	13	1	9	17	3	4	8	12	14	10	2

In this particular area of pure achromatic hues, the lightness parameter would be the most responsible parameter for visual perception of achromaticity that enables the observer to distinguish the blacks from whites and grey. But in real conditions, the ideally achromatic surface as well as the ideally blackness, cannot be achieved and the boundaries of purely achromatic black or grey against the dark achromatic with noticeable hue cannot be strictly defined since the experience of blackness and achromaticness finally is a product of psycho – physical response of visual system and are subject of various influences [1-10].

The observer as potential customer expect the sense of absolute achromaticity from blacks and greys with no sense of dominant hue. The problem is that the range of achromatic hues perception varies significantly from one observer to another, while colorimetric parameters which objectively define the colour and quality of achromaticity are not in accordance to visual experience.

According to results of visual assessment (Table 1), the observers defined the samples 1, 6, 14, 15 and 20 as the most matching to a reference sample (sample 11). The samples mentioned were ranked from 2 to 6. The samples mentioned were, due to a very low lightness value, visually assessed as achromatic black. Samples 8, 16, 12 and 19, were also defined as achromatic black, although the objective a*/b* values were a*/b* > ± 1, which resulted in higher C* values. On lower lightnes levels where lightness value are L* = 12,6 – 16,6, a human eye is not able to distinguish the dominant hue and observe samples as black. Samples 3, 4, and 9 were assessed as boundary chromatic – achromatic, which were expected due to obtained higher lightness level L* and chroma C*. Lightness value L* is 20,3 for sample 3; 19,6 for sample 4 and 18,7 for sample 9. On such lightness levels the samples will be perceived as greys (dark grey), if the criteria of minimal chroma C* is satisfied. Samples with higher chroma values, emphasized for sample 3 (C* = 8,8) and 9 (C* = 10,9), were experienced, in dependence on hue value (h*), as greys with certain chromatic shade. Samples 3 and 9 were observed as bluish – greenish greys, while the sample 4 was experienced as reddish grey.

In further work, the analyses of objective L* and C* values relationship has been performed, (Figure 2a). The results of visual ranking obtained based on visual assessment are compared to objective L* and C* values, on Figure 2b.

Definition of achromatic colours are based on L* and C* relationship. The L*/C* relationship presented (Figure 2a) confirms that the visual perception of achromatic hue will occur if the criteria of chroma C* parameter set as C* 1 is satisfied, which defines the minimal partition of dominant hue. Based on lightness difference the observer will perceive achromatic hue (black, grey and white), but will not sense any specific hue.

On histogram of comparison of objective L*/C* values with results of visual ranking (Figure 2b), it can be seen that the results of visual assessment of samples 1, 6, 11, 14, 15 and 20, are in accordance to objective evaluation. As for other samples, with chroma value C* > 1, certain discrepancies can be observed in visual and objective assessment which imply certain confusion of an observer.

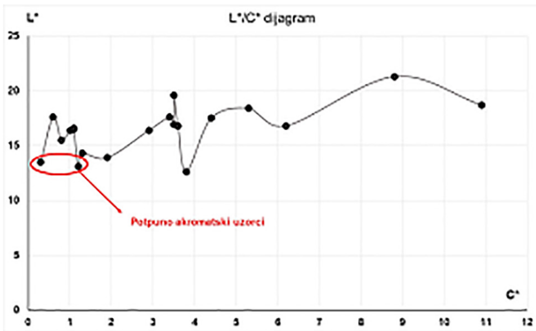

Figure 2a. L/C* diagram of tested samples*

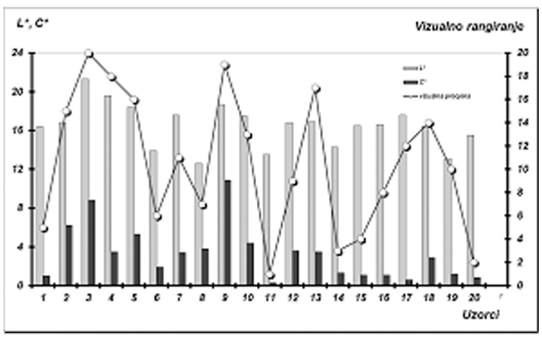

Figure 2b. Ranking of samples based on visual assessment, compared to objective L and C* values*

In further work, based on reference sample (sample 11), the calculation and analyses of colour difference obtained according to two different formula, CIELAB and CMC (l:c), were performed. It must be pointed out that the value of total colour difference is highly important, but also an general indicator of discrepancies among samples compared. It is often the case that the instrumental control confirm the colour difference among samples in the range of tolerances set by the ISO standards, while observer perceive certain differences and doesn't accepts the sample. So it is very important to perform the analyses in single colour parameter differences, ΔC*, ΔL* and Δh*.

In further work, besides the analyses of total colour difference value, ΔE, for two compared formula, the analyses of differences in hue Δh*, chroma ΔC* and lightness ΔL* parameter for two tested formula, has been performed (Figures 3, 4a, 4b and 4c).

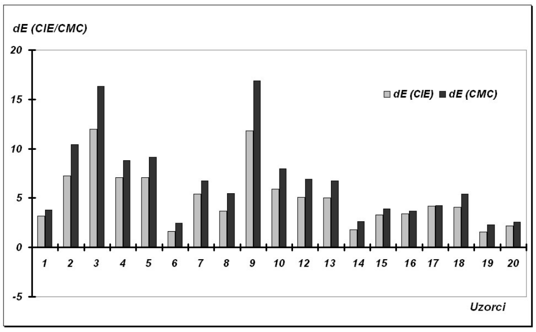

Figure 3: Relationship of total colour difference ΔE, for two compared formula (CIE and CMC)

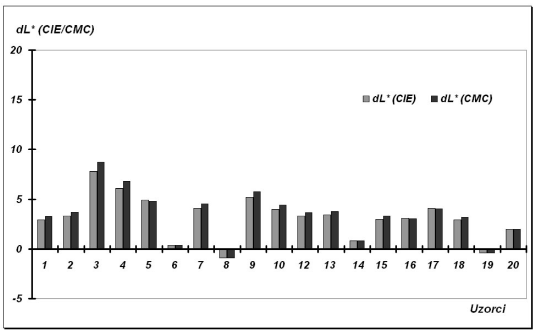

Figure 4a: Relationship of lightness difference ΔL for CIE and CMC formula*

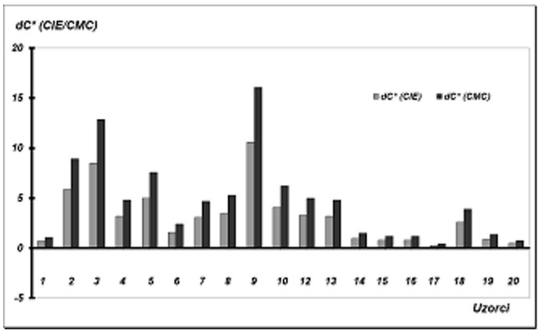

Figure 4 b: Relationship of chroma difference ΔC for CIE and CMC formula*

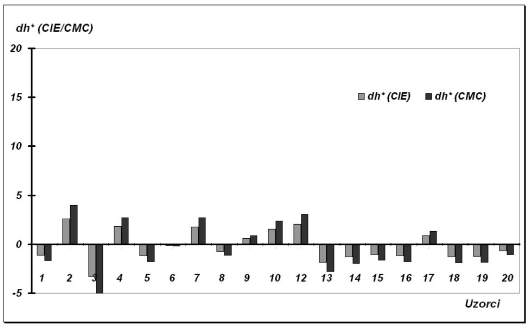

Figure 4c: Relationship of hue difference value Δh for CIE and CMC formula*

The results show certain differences between two tested formulae in evaluating the total colour differences. The values obtained with CIE formula are, in general, lower from those obtained by CMC (l:c) formula (Figure 3), implying the lower selectivity of CIELAB formula.

The difference between two compared formula is emphasized for samples 3 and 9, which are characterized with lightness value L*>16 and hiher chroma C* value. So, according to that, the samples mentioned cannot be defined as achromatic, but as boundary chromatic – achromatic, where the dominant hue h* is becoming significant.

Precisely in that area, the differences in ΔL*, ΔC* and Δh* calculations according to CIE and CMC(l:c) formula, are the most emphasized, while the results obtained are implying the higher reliability of CMC(l:c) formula, especially while comparing the achromatic samples with boundary chromatic – achromatic samples.

CMC (l:c) formula includes two additional factors for colour difference tolerances quantifying, l and c, which are taking into account also the differences in hue parameter. In a final version of formula the factor for lightness difference tolerances, l, was set as value "2", setting the tolerance factors relationship l:c = 2:1, allowing the higher tolerances for lightness differences. The CMC(l:c) formula, also includes additional SL, SC and SH factors, which defining the size of tolerance ellipsoid around the reference sample, considering the coordinates of lightness, chroma and hue [4, 5].

For S_L factor it is characteristic that for lightness values L*<16 it is set as constant value and it does not change with the change in lightness value L*. This imply better accordance of CMC(l:c) formula with visual evaluation in compare to CIELAB. It was established that in the area of lightness value L* 16 there is no visual selectivity for dominant hue differences [4, 5].

On figure 4a, the comparison of ΔL* value for CIELAB and CMC(l:c) formula is presented. It can be seen that for samples 6, 8, 14, 19 and 20, the equable ΔL* values was obtained for both compared formula. The reason is precisely in S_L factor calculation and ΔL* value for CMC(l:c) formula. As it was said, for samples mentioned the lightness value L*<16 was obtained, meaning that the S_L factor is equal for those samples and is set as value 0,511, according to formula 3. Magnified by the value of lightness tolerance coefficient „l" = 2, the S_L factor is set on value 1,02, which has no further influence on final result of ΔL* calculations. Significant differences for lightness value can be seen for samples 3, 4, and 9, which, according to their L*/C* values are belonging to boundary chromatic – achromatic area, while the reference sample (sample 11) are belonging to pure achromatic area. The higher differences values are here obtained for CMC(l:c) formula, which is in accordance to the earlier statement that precisely in cases of achromatic comparison to boundary chromatic – achromatic hues, CMC(l:c) formula obtaining better reliability of the results.

Significant differences between compared colour difference formula were also obtained in hue difference, Δh*, and chroma difference, ΔC*, calculations.

On Figure 4b and 4c, ΔC and Δh* values obtained according to CIELAB and CMC(l:c) formula are showed. It can be seen that the total colour difference (ΔE) calculation according to CMC(l:c) formula, includes S_C factor (4) which is calculated based on chroma C* value of as reference sample (C*S), which imply lower tolerance on chroma differences. This can be confirmed by the significantly higher ΔC* values obtained according to CMC(l:c) formula, in compare to ΔC* values obtained by the CIELAB formula (Figure 4a). Such selectivity of CMC(l:c) formula, in chroma parameter which is key parameter in the area of achromatic hues, confirms the optimal applicability of CMC(l:c) formula in that specific area.

It is necessary to mention that the calculation of dh* value, through the S_H factor includes also chroma factor S_C. Such setting of mathematical expression is in accordance to visual perception, because the visual experience of hue is in dependence to chroma. On low levels of chroma, the human eye will not observe the difference in dominant hue but observes only achromatic. With increase of chroma value, the human eye starts to distinguish chromatic hues. It is important to mention that CIELAB formula in the expression for Δh* calculation also includes chroma, but in CMC(l:c) expression it is more emphasized with addition of SH tolerance factor [4, 5, 8, 9, 10].

Although the samples tested in this paper, according to their a*/b* coordinates, are placed in all four quadrants of a*/b* space (Figure 1), the differences obtained in hue parameter regarding the reference sample, according to both colour difference evaluation formula, are not emphasized. The highest Δh* value regarding the reference sample and also the highest Δh* value regarding the compared colour difference evaluation formula, was obtained for sample 3, which is characterized with highest lightness value L* in a group of tested samples (L*=20,3) and relatively high chroma value, C*, in compare to other tested samples (C* = 8,8). For the sample mentioned, which was visually assessed as boundary chromatic – achromatic, the higher Δh* value was obtained for CMC(l:c) formula in compare to CIELAB. That confirms earlier mentioned fact that the CMC(l:c) obtaines better agreement of objective colour differences with visual experience and that, precisely in specific chromatic – achromatic area, the better selectivity of CMC(l:c) formula has been confirmed.

4 The Example of Achromatic Hues Matching in Graphic Design

According to theory of design [12], graphic design can be defined as visual design, which confirms, according to literature, that the most important is final impression of an observer. Fred W. Billmeyer, have said: „No one accepts or rejects certain colour combination based on numerical evaluation but exclusively based on visual appearance of a colour".

On examples showed on Figures 5 and 6, the short analyses of visual experience of achromatic hues matching has been presented, with aim of pointing out some concrete problems in practice. On Figure 5, the example of dark grey and black achromatic hues in visual identity design of famous New Zeeland wine producer, Black Estate, has been showed. The visual identity of the product line is based on producer name (Black), which is also the dominant colour used in web design and other aspects of the brend, followed by other dark achromatic colours with minimal accents of certain chromatic hues.

The Figure 5a shows the original web site design and also a packaging design, with highly representative visual experience of pure achromatic grey and black hues, with no any experience of dominant hues. The only parameter used in gradation between white, grey and black is the lightness parameter. The perfectly matched combination of black and grey has been obtained, with no sense of dominant hue. Such achromatic area is suitable for addition of certain chromatic details which are accented by the achromatic surrounding without competitive relationship. The example 5b is example of an mistake which can be caused by moving grey hues towards certain chromatic, obtaining specific boundary chromatic – achromatic variation. In dependence on characteristic of an observer, the chromatic hue will be more or less experienced. On Figure can be seen that the shades of grey are not pure achromatic as is expected, but certain chromatic reddish shades are observed. Not just that the experience of pure achromatic is disturbed but the problem of chromatic details matching with background which is no longer pure achromatic, occurs.

Figure 5a: the original design

Figure 5b: the example of mistakes in achromatic hues matching

Figure 5ab: The example of web design and visual identity design based on dark achromatic hues

Figure 6 shows the example of mismatch of grey shades which are in scale from pure achromatic to boundary chromatic – achromatic shades. The example of web design based on scale of achromatic grey is showed.

Figure 6a is showing the original design. The highly satisfactory matching of grey shades used, can be seen. It can be said that the perfect gradation of grey shades, with minimal chroma value and minimal partition of dominant hue, has been obtained. With such settings, the visual perception of pure achromatic hues has been assured. On Figure 6b, the example of an mistake is showed, which occurs due to a characteristic of boundary chromatic – achromatic property of two grey shades used in composition. It can be seen that certain grey shades are perceived as reddish grey and greenish grey.

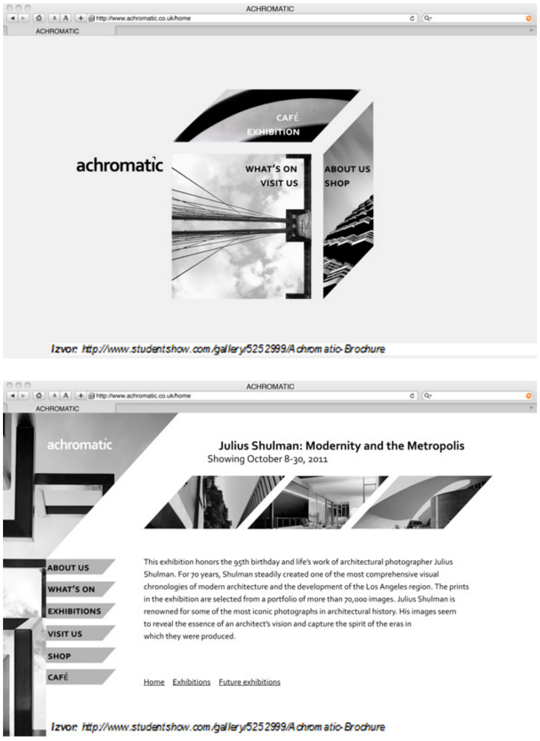

Figure 6a: The original design

Figure 6b: The example of mistake in achromatic hues matching

Figure 6ab: The example of mistake in matching the achromatic hues in web sites design

5 Conclusion

In colour application regardless is it in industrial practice or in artistic expression, the understanding of nature of human colour perception, is essential, as well as the knowledge of colour influencing the psycho – physical experience of an observer. In process of achromatic colours application, the demands on quality of achromatic colours reproduction are very high. The observer, as potential user, expect from blacks and greys the highest possible achromaticity, with no perception of any trace of dominant hue. Although, due to a sloth of a human eye there is certain lower perceptual selectivity in achromatic area, in some cases certain differences visual experience of black and achromatic hues in general, can occur.

The analyses presented in this paper is an contribution to researches and experimental work that has been performed in the area of colour, which imply the complexity of objective colour difference evaluation system application as well as visual assessment, in specific achromatic area. It is the aim to find the answer to a question is it possible to determine the concrete boundaries between achromatic and chromatic – achromatic area.

From the aspect of visual perception, this boundary is changed from one observer to another, and it was confirmed in this paper as well as according toliterature, that the results of objective colour and colour difference quantifying in this specific area, are unreliable. It has been confirmed that the achromatic hues matching cannot be achieved exclusively based on objective colour and colour differences evaluation but the analyses must be performed by systems which presenting the magnitude of visual perception of colour or respecting and combining the objective evaluation with subjective assessment.

The results confirms that for satisfactory achromatic hues matching, following criteria must be followed: the a*/b* values must be set on values ±1 in order to assure the minimal chroma value, C*. Also, from the aspect of the hue, although it was confirmed that under the setting of lightness value $L^*<16$ and a*/b* and C* criteria mentioned above, human eye will not obtain the hue selectivity, it is recommended that the achromatic hues are matched also saccording to hue parameter, h*. Meaning, to represent the achromatic scale of the same dominant hue. Such matching is also important on higher lightness L* values, when human eye experiences the scale of greys, as well as for boundary chromatic – achromatic samples.

Finally, it can be said that that the complementary knowledge from theory of visual perception and theory of harmonious colour matching as well as the knowledge and understanding of different objective colour and colour difference system specificity, are essential in colour application. It has been shown that in specific achromatic area and even more emphasized in boundary chromatic – achromatic area, neither by objective colour and colour differences evaluation nor exclusively by means of visual assessment, certain colour differences cannot be precisely defined. So it is essential to set the criteria in aim of assurance of positive colour matching. Such criteria must be set flexible regarding the specificity of every single case.

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