REALWORLD AND SOFTWARE SIMULATED ILLUMINANTS IMPACT ON THE COLOR CONSTANCY OF PRINTED DESIGN PRODUCTS

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Abstract: The presented paper aims to evaluate the impact of real world and software simulated illuminants, used for color samples observation, upon the color reproduction of printed design products. The objects of research represent three design concepts for a cover presentation of the „Bulgarian tourist chamber". Based on comparative analysis, the resulting data will help to determine the final design product, having best quality color reproduction in various real world observation environments. The goal is, using color management, to find the design with best color constancy upon illuminant change. The three design cover concepts are analyzed numerically and the color errors associated with the process of soft proofing them are determined. The aim was to determine the color differences at the beginning of the research between the digital original designs and the expected results from printing them on a digital printer, simulating the final print conditions – offset process. In this way the client and the designer will be able to get actual impression how the product looks in standardized observation conditions when printed and to make the appropriate choice. The research uses calibrated and profiled to D50 display as well as software for color gamut visualization in a device independent 3D LAB color space of the design color space and of the output print profile. In that way the designer can determine whether the colors used in the project are actually achievable in print using digital or offset reproduction processes. Using this procedure, the accuracy of color reproduction of the printed product, compared to the digital original, is improved. The color shifts, related with using different rendering intents when transforming the design color for printing, are also visualized. After the analysis of the soft-proofs the three designs are printed on a digital printer using hard-proofing settings for offset print condition. Next, they are subjected to observer evaluation using different real-world illuminants. The used illuminants are: simulated D50 light in a light booth, standard office fluorescent illumination, natural daylight and incandescent light. In that way, the designer and the client can easily identify potential color shifts in the printed items when the illuminant is changed – a common practice in real-world, where the end users of the design product don't have standardized lighting. Using this research, the most appropriate design variant having the biggest color constancy upon change of illuminant can be chosen – illuminant metamerism. In addition, the color rendering capabilities of the used in the research illuminants are analyzed using spectral measurement data. Apart from real-world observation conditions analysis, the color constancy of the colors in the three design versions is also evaluated using software-simulated illuminants. In this way it is possible to evaluate the impact of a larger number of illuminants on the three design versions. The main colors of the printed design versions are spectrally measured and analyzed in a device independent Lab color space using software for color analysis and spectral simulation of illuminants. Different color palettes are obtained depending on the simulated illuminant. These palettes are used for subjective evaluation of the illuminant metamerism of the three tested design versions.
Keywords: color management, illuminant metamerism, color reproduction, product design, standardized illuminant, color constancy

1. INTRODUCTION

A well-known fact from color management is that the illuminant, used for observation strongly affects the resulting color sensation in the observer. For this reason the current ISO 3660:2009 specifies strict viewing conditions for observation of printed materials. In the area of prepress and print, each illuminant is characterized by its spectral-power distribution, the color rendering index - CRI and its metamerism index. In fact the various values of these parameters when using different real world illuminants lead to perception of a color as a different color under various illuminations – illuminant metamerism. This effect can greatly influence the color perception of a given printed design material and lead to opened disputes between customers and design authors [1].

The presented paper aims to evaluate the impact of using various real world and software simulated illuminants, used for observation, upon the color perception of printed design products. The objects of research are three design concepts of a cover for the "Bulgarian Tourist Chamber". Based on comparative analysis, the obtained data will help to choose the final design concept, having the best color reproduction capabilities in various real-world viewing conditions. Using color management methods, the authors are aiming for achieving maximum color stability of the color perception when the observer illuminant is changed.

2. NUMERICAL ANALYSIS OF SOFT-PROOFS OF THE THREE COVERS DESIGN CONCEPTS

A numerical analysis with color shifts determination is performed when the three cover design concepts are soft-proofed. The goal is to determine the expected color errors between the digital source originals and their hard-proofed offset reproductions on a digital printer. In this way the client and the designer have the opportunity to get an actual idea of how the product will appear in standardized viewing conditions when it is actually printed and to make the proper choice. The analysis uses a calibrated and profiled computer display and specialized software for color gamut visualization, in a device independent 3D LAB color space, of the output printer ICC profiles - ColorThink Pro. These tools enable the designer to determine whether the colors used in the project are actually achievable when using digital or offset print conditions. The accuracy of the color reproduction of the printed product as compared to the digital original is greatly improved using this procedure. The color shifts during printing of the three design concepts with usage of different color rendering intents are also visualized [2].

Figure 1 shows a numerical analysis of the color shifts during soft-proofing a digital printer output process. The color transformations from the source to the output digital printer color space are clearly seen. The used rendering intent is relative colorimetric – this is the most commonly used intend because it preserves to a great extent the color relations in the original image's colors. The expected color errors during this transformation, expressed in numerical form, are shown to the right on the figure. The software correctly predicted the greatest color errors to lie in the light areas (especially the white color). This is normal, because at present the commonly used white paper for digital printing is heavily whitened using OBAs and does not correlate well to the white points of digital CMYK color spaces using pro project designs. The relative rendering intent color transformation is very effective in this situation – the source and target white points are compared and all out of the printer gamut colors are proportionally shifted with the goal of preserving the relations between them with respect to the new white point. Logically such color shifts are clearly seen and predicted throughout the entire analyzed soft proofs. Form figure 1 it can be concluded that if this image is printed on the simulated digital printer, using this paper, the result will exhibit clearly visible color shits compared to the digital source original, but thanks to the mechanisms for white adaptation in the human eye, the correct color relations in the image will be preserved.

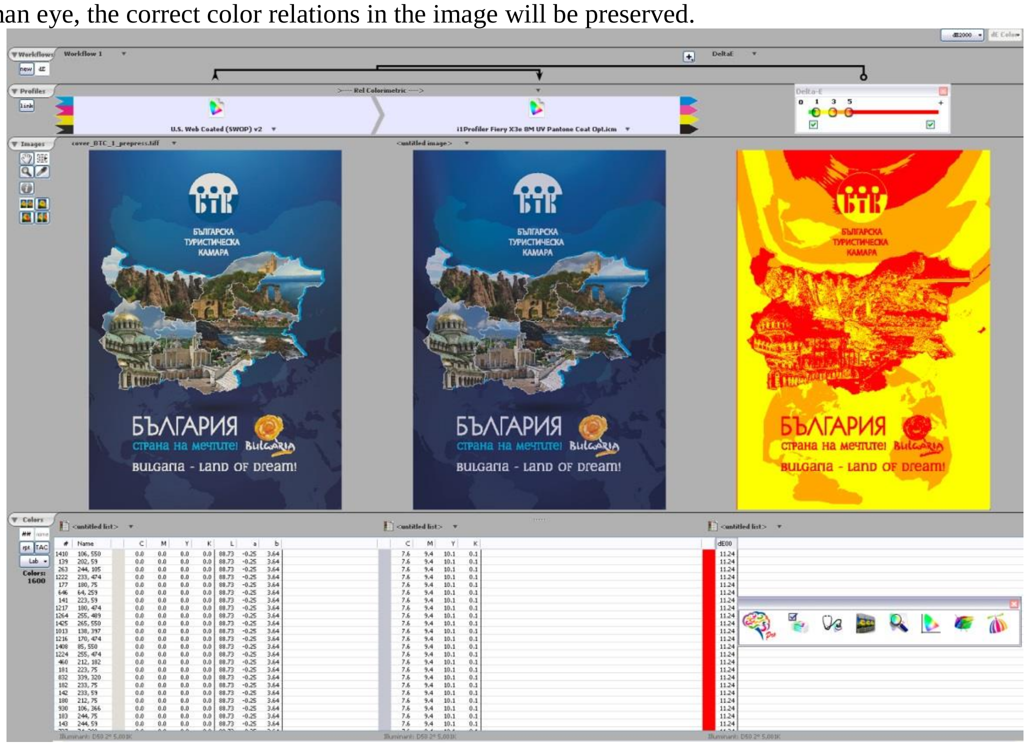

Fig.1. Numerical analysis of the color shifts of a design cover project during soft proofing

Figure 2 shows a numerical vector analysis of the same color shifts from figure 1 in a device independent LAB color space. The vectors on the figure represent the color shifts. The beginning of each vector shows the source digital original color and its end represents the resulting color after transformation. The length and spatial orientation of the vectors denote the magnitude of the color error as well as the hue, lightness and saturation of the image colors. The left figure shows the vectors painted in actual image colors, while the right one is color codes with the magnitude of the computed delta E2000 color errors. It must be noted that delta E2000 color errors, greater than 5 units are perceived by a human observer as objectionable.

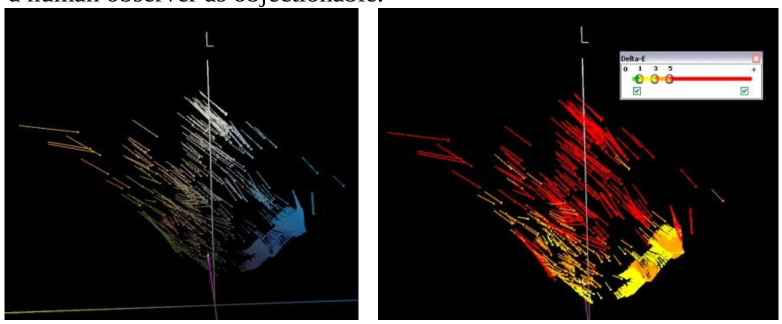

Fig.2. Color errors vector analysis in a device independent 3D LAB color space

3. SUBJECTIVE ANALYSIS OF THE PRINTED DESIGN COVER CONCEPTS UNDER VARIOUS ILLUMINATIONS AND NUMERICAL ANALYSIS OF THE COLOR REPRODUCTION PARAMETERS OF THE USED ILLUMINANTS

After the analysis of the soft proofs the three design concepts are printed on a digital printer using simulation of a offset color gamut – hard proofs. They are then subjected to a subjective evaluation under various illuminations. The used illuminants are D50 simulated light in a color viewing booth; common fluorescent office lighting setup; natural daylight and an incandescent illuminant. In this way the designer and the client are able to identify possible color shifts in the printed design projects when the illuminant is changed – quite a common situation in practice when the end users don't observe the design product in standardized viewing conditions. Using this analysis, the most appropriate design concept that exhibits the least color instability upon illuminant change can be determined.

In the current research an analysis of the color reproduction capabilities of the used real world illuminants is also performed. Figure 3 shows the measured illuminants spectral power distributions. Under each measured spectrum a comparison is made versus an ideal spectrum of an illuminant having the same correlated color temperature. The most important for the research parameters on the figure are the illuminants color temperature; the color rendering index (CRI > 90 for proper color reproduction) and the spectral power distribution [3]. From the figures it can be seen that the viewing booth and natural daylight will exhibit the best color reproduction capabilities and the color shifts of the observed design concepts under these illuminants will be very small. The incandescent illuminant has very good CRI index, equal to that of natural daylight. This is a prerequisite for good color reproduction, but the small power content in its spectrum in the short wavelengths will lead to warmer colors. The fluorescent illuminant will cause the greatest color shifts because of its low CRI index. The simulations, analyses and conclusions made so far and in chapter 4 must be tested using subjective evaluation of the three design concepts performed by a trained human observer in real world viewing conditions. Such an analysis is made in this chapter. The results are presented in the next sub-chapters and can be summarized as: in relation to specific features of the design concept, the three designs are developed using similar coloristic approach. The used colors are in the short wavelength spectrum and more specifically in the blue gamut. Because of this, the differences in the color shifts of the three designs are small; except for the cases when there is an optical illusion due to the phenomenon "simultaneous contrast" (the object's color changes depending on its surrounds).

3.1. D50 viewing light booth Just Normlicht Color Communicator 1

The results from the subjective analysis of the three printed design concepts show very good color reproduction with lack of color shifts in the saturation of the colors. However, there are visible shifts in the color hues – the blue colors in the three hard proofs have warmer hues with added magenta. This is most clearly seen in the images, which are an essential element of the design's composition. The added magenta nevertheless adds greater brightness in the color of the Bulgarian logo, which makes it a distinguished composition center that quickly attracts the observer's attention. The lightness of the designs colors is slightly shifted – the hard proof ones are darker compared to the digital original.

3.2. Common fluorescent lighting setup

The results here show similar color shifts, with the exception of variant 2, which has slightly higher hue shifts, compared to the others. The most clearly seen difference is in the "cyan" color of the design, where there is a shift in the hue, lightness and saturation – it is lighter and more saturated under this type of illumination. The results also show differences in the color reproduction of the designs: there is a visible lack of the color „magenta", seen also in the logo of Bulgaria; there are also deviations in the lightness – the colors of the photos here appear darker than under D50 viewing light booth.

3.3. Natural daylight

Under this illuminant there is a negligible deviation in the color reproduction. Visible slight differences are observed in the saturation of the colors, which is also increased in the color hues that are shifted towards the short wavelengths. Because of this, the utilized in the design colors from the blue gamut appear clearer and brighter with visible lack of color shifts in the color reproduction. There are no visible color shifts in neither of the three design concepts.

3.4. Incandescent illuminant

The results here show a clearly defined thorough color shift towards the warmer gamut (the longer wavelengths). In this way there is also a visible shift in the color hues and the shifts are mostly visible in the warmer colors – in the logo of Bulgaria and in the images. There is also a shift in the lightness of the colors – under this illuminant they appear darker, compared to D50 light booth.

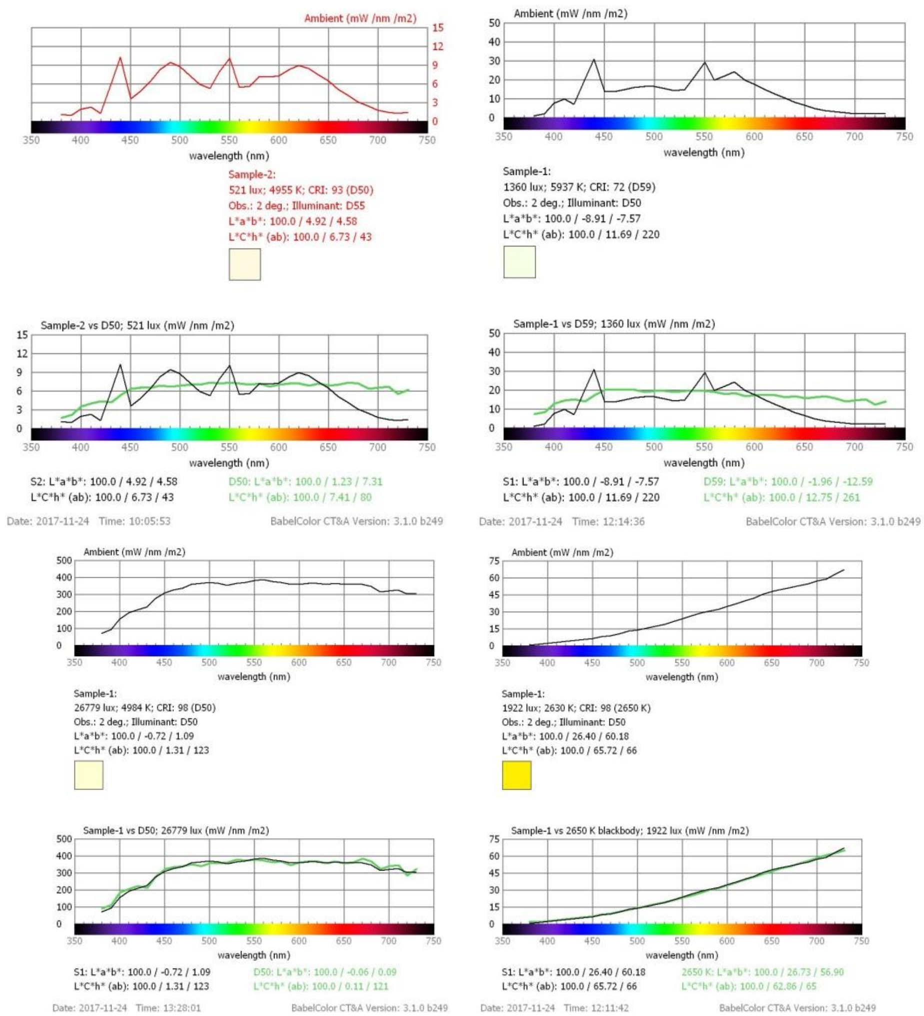

Fig.3. Real world measured illuminants spectra used in the subjective analysis: D50 light booth; fluorescent office illumination; daylight and incandescent illuminant

4. EVALUATION OF THE COLOR STABILITY OF THE COLORS OF THE THREE DESIGNS USING SOFTWARE SIMULATED ILLUMINANTS

The evaluation determines how each of the measured colors from the three design concepts will be perceived under various illuminations and what its color stability is. The index that characterizes that stability is defined as Color Inconstancy Index - CII. The CII computed in this paper is based on CIECAT02, the latest approved standard for Chromatic Adaptation Transforms (CAT). The CAT matrix used in CIECAT02 is a variant of a simplified Bradford CAT, where some non-linear parameters are omitted, and with a matrix which is further optimized in regards to many experimental data sets. The recommended daylight reference illuminant is D65. This is consistent with the use of L*a*b* as the color difference space, since it is often considered that the L*a*b* space is most uniform for D65 [4]. Figure 4 shows the results from the analysis of six essential to the design concepts colors form one of the three printer covers using software simulation of two actually measured illuminants – daylight and D50 light booth. On the figures the parameter concerning the current research are the computed CII values describing the design concept's color stability. Table 1 shows the computed color inconstancy indexes (CII) for all measured colors from the three printed design concepts, used also for subjective evaluation under different illuminants in chapter 3.

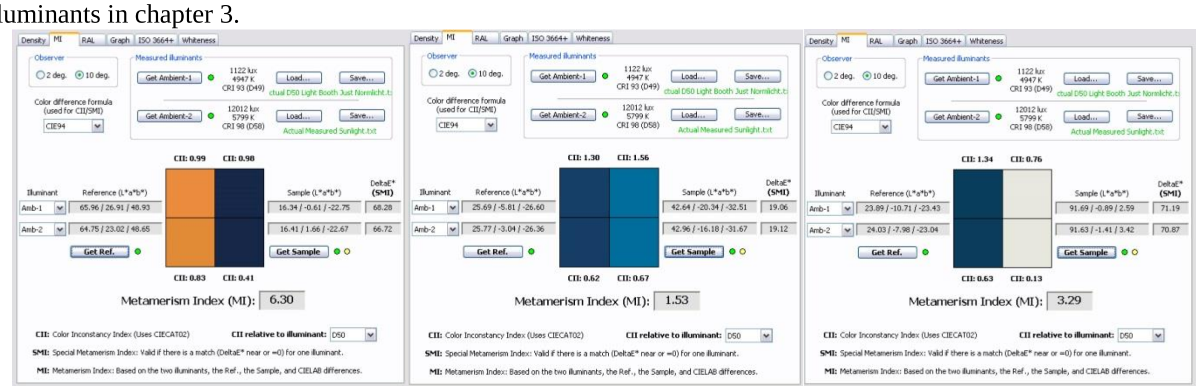

Fig.4. Results from color stability evaluation of six essential colors from the researched printed design concepts

Computed color inconstancy indexes CII (deltaE2000)												
Essential color	D50 light booth			Fluorescent lights			Natural daylight			Incandescent light		
	Design covers concept number:											
	1	2	3	1	2	3	1	2	3	1	2	3
	0.65	0.57	0.59	1.30	1.68	1.65	0.18	0.19	0.18	3.30	2.80	2.70
	0.76	0.90	1.06	1.46	3.43	4.30	0.17	0.12	0.10	3.92	2.40	2.29
	0.85	0.92	0.91	7.25	7.35	7.41	0.25	0.25	0.26	6.67	7.00	7.07
	1.12	1.04	1.17	4.13	5.01	5.09	0.03	0.14	0.19	2.89	3.06	3.87
	1.00	0.49	0.47	4.02	3.63	3.64	0.09	0.08	0.08	2.28	1.02	0.83
	0.61	0.61	0.60	1.46	1.37	1.38	0.04	0.05	0.04	0.53	0.57	0.53

Table 1. Results from the color stability evaluation for six essential colors from the three printed design concepts, "illuminated" by four software simulated actually measured illuminants

Figure 5 shows visually the color shifts of six measured colors from each of the three printed design concepts when using a so called virtual light box able to simulate up to four different standard illuminants at the same time. This is a very useful tool for quick visual analysis of actual measured colors from printed originals. It is very helpful for designers and clients when there is a need to make the correct decision about the color stability of a certain project. When there is also a need for a numerical analysis and accurate determination of the color shifts upon illuminant change, especially when an evaluation of the color stability under nonstandard illuminant is needed, the method described in figure 4 is used, along with spectral analysis and determination of the color rendering abilities of the measured illuminants [5].

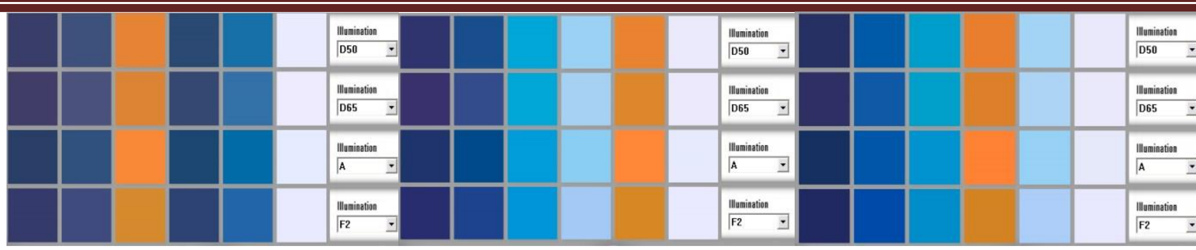

Fig.5. Visual color shifts of six essential measured colors in a virtual light box (var.1 to the left; var.2 in the middle and var.3 to the right)

5. ANALYSIS OF THE RESULTS AND CONCLUSIONS

With the help of the analysis from chapter 2 the designer and the client have reach an agreement upon the expected color differences between the digital originals of the three design concepts and their printed hard proofs. Consequently they are subjected to a subjective analysis aiming to evaluate their color stability upon observation under various illuminations. Parallel to that, it has also been performed a simulation visual and numerical analysis of the color inconstancy of the suggested designs. Apart from the orange colors in the designs, there are no other expected big color shifts in the three designs upon illuminant change. Because this color is not predominant in the suggested designs this shift is acceptable. A notable exception is the fluorescent office illumination – because of its poor color rendering index (CRI=72), all simulated colors exhibit considerably larger color inconstancy index values. It can be said that this type of illumination is not appropriate for evaluation of the suggested designs. Because the concussions so far are based only on software simulations it is beneficial that they are confirmed or disproved by real observations performed by a trained human observer in real world conditions.

After the performed evaluations by a trained observer it can be deduced that there is a similar color stability of the three design concepts, because the differences in the color shifts of the reproductions under various illuminants are negligible. Because of that the authors recommend that the leading factor when choosing the final version of the design would be the aesthetic and emotional pleasantness, which each of the designs invokes in the observer. Therefore it is necessary to take into account the end-user's expectations and attitude for the shape and coloristic features of each of the concepts as a priority factors, considering the presented in the paper features of quality color reproductions.

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