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THE INFLUENCE OF THE SURROUNDING SPACE ON THE LIGHTING CONDITIONS IN A PHOTOGRAPHIC SCENE

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Abstract: *Lighting conditions are one of the most important factors for good photographic exposure. In enclosed spaces, like a photography studio, we can control the light in several ways. We can adjust the type of light source, the shape of the light source, its intensity, and in some cases the colour temperature of the emitted light. The distance of the light source from the observed photographic scene affects the amount of light that reaches the desired target, and therefore the actual lighting conditions on the photographic scene. However, the environment surrounding the photographic scene is often overlooked. The light emitted interacts not only with the objects within the photographic scene, but also with any obstacle in the path upon which a light ray falls. Light rays can be reflected, partially reflected, absorbed, or scattered from any surface in the immediate vicinity of the scene, depending on the material properties of the objects they encounter. In the case of reflection, the observed scene is additionally illuminated by the reflected light, since the reflecting surface in the near environment acts as another light source. Light-absorbing surfaces, on the other hand, do not affect the scene in the same way, since the light is absorbed and not multiplied by the reflection. Reflections from the surrounding environment can therefore affect the intended lighting conditions of the observed scene in ways that we did not anticipate.*
This study focuses on the influence of the surrounding space on the lighting conditions in an observed photographic scene by comparing the lighting situations in a scene from a photographic studio with a diverse environment and from a darkroom with minimal environmental influence. Halogen, LED, and xenon light sources are tested individually, illuminating the test scene with different intensities and colour temperatures. The illumination conditions at the observed photographic scene are described using spectrophotometric methods and image analysis to numerically describe the differences in uniform illumination of the flat scene surface. The results are analysed and compared to illustrate the influence of the surrounding space. Based on the results, guidelines for a suitable test environment in photographic research are proposed.

Key words: *photography, lighting conditions, photographic scene, light reflection, colour properties*

1. INTRODUCTION

When we think about photography, there is always one important thing to consider - light. As the word photography itself suggests, when we take pictures we are literally painting with light, so conditions are always the most important factor affecting the end result. When it comes to studio photography, there is one big advantage compared to outdoor photography: we have complete control over the photographic conditions. A typical photographic setup usually takes into account three main variables: the surrounding space, the lighting conditions and the camera exposure. Changing one of these three variables will affect the effect of the other two and change the outcome. Understanding each of these conditions is therefore crucial to being able to fully control the photographic scene.
The way we use lighting equipment in the photographic scene can vary greatly, but all uses are based on an understanding of the physics of light, such as light intensity, softness/hardness of light, correlated colour temperature (CCT) (McCamy, 1992), colour rendering index (CRI) (Davis & Ohno, 2009), type of light and also how light is emitted, reflected, absorbed, transmitted, reflected, etc (Bitlis, Janson & Allebach, 2007). Having in mind that the lightning conditions are determined not only by the light source but also by the environment, it is important to understand the environment as well.
The colour of the photographic scene is one of the factors that define the surrounding space and has a great influence on the lighting conditions because of the reflected light. The use of different coloured backgrounds can therefore be a very powerful way of defining the look of the final photographic result, and in the creative process it is very common to use very chromatic photographic surroundings. However, when we consider the need for accurate colour reproduction, the way in which light is reflected from the scene can have a major impact on the result. Reflected light can in some cases even decrease the quality of a captured image (Raskar et. al., 2008).

The typical photo studio is usually white, and different colours are achieved by using backgrounds, which are usually made of paper, textiles or by painting walls. Choosing the right background for the scene is, as mentioned, not only a matter of artistic expression, but we also need to keep in mind the quality of colour reproduction. There are different ways to deal with light in a photo studio (Gunde et. al., 2009; Hough, 2013; Štampfl, Možina & Ahtik, 2021). There are also different approaches to normalising colour reproduction in relation to the colour of the surrounding space using colour management (Ahtik, 2017), where we calculate ICC (Morris, 2005) or DNG (X-Rite, 2022) colour profiles. However, the most important research question remains how big the influence of the environment on colour reproduction actually is. Research therefore focuses on the use of different coloured scenes in combination with different light sources.

2. METHODS

2.1 Test environment and photographic scene

To test the influence of the surrounding space on the lighting conditions at the observed scene, we tested five different experimental setups, as shown in *Figure 1*, with additional variations within the first. The first four test environments were in a photographic studio, mimicking the general use of the space and arrangement of objects for photographic projects and research. In setting *(a)*, a series of 5 paper backdrops and two reflective surfaces were used in front of a white wall, in *(b)* a series of photographic light sources with light-shaping attachments were placed in the background with the front of the shaper facing the scene, in *(c)* the light-shaping attachments were facing the other direction, while in *(d)* two of the light sources were facing the wall and the other two were facing the setup. The fifth setup *(e)* was located in a darkroom whose walls were painted with low reflectance black paint. A photograph of the setup *(d)* is shown in *Figure 2*.

A black, uniform surface served as the base for the photographic scene. A *GretagMacbeth ColorChecher DC* test chart was placed in the centre of the plane. The scene was located 1 m from the background at a height of 0.8 m. The *Lupo Superpanel Dual-Color* LED light panel with a colour temperature of 5040 K was used to illuminate the scene, placed 1.5 m from the scene and aimed at the background from a height of 1.5 m. This allowed for a uniform illumination of the scene, despite having only one light source.

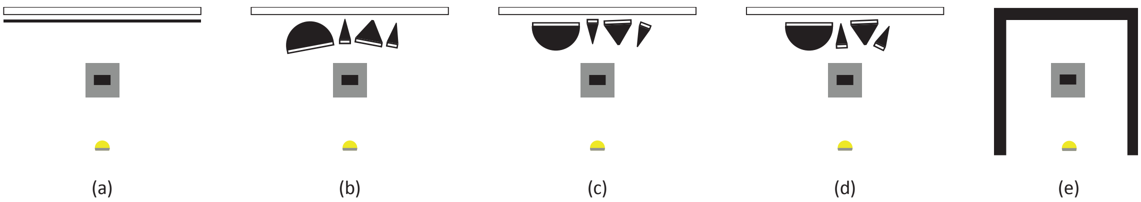

Figure 1: Test environments: (a) paper backdrops in a studio, (b) white background in a studio with white surface objects, (c) white background in a studio with mixed-colour surface objects, (d) white background in a studio with black surface objects and (e) darkroom.

Figure 2: Photo of test environment from Figure 1(d).

2.2 Data capture and analysis

A camera was placed above the centre of the test chart, which allowed us to take a photograph of a flat area of the scene. A series of photos were taken in all 11 conditions in specified test environments. We used a Nikon D850 camera with AF -S Nikkor 50mm f/1.4G lens with ISO speed set to 100, white balance set to a manual setting of 5040 K, aperture set to f/5.6 and 1/40 second exposure time. The fixed settings allowed for comparison between test environments.

All images were captured in the native Nikon raw format (NEF) and processed before final analysis. Photos were imported into *Adobe Photoshop Lightroom Classic* (version 11.2), rotated, and cropped to the original alignment marks on the *ColorChecker DC*. The images were not processed in any way and exported in JPG format in sRGB colour space, as this is a common choice for photographers.

We developed a Python programme with a set of open-source libraries, whose actions are represented with the following pseudocode:

```
import images
read RGB values of all patches on all images
import measured RGB values of all patches
convert all RGB values to CIE XYZ
convert CIE XYZ to CIE Lab
calculate colour differences dE00 for test images and imported colour values
calculate colour differences dE00 for test images and darkroom image
convert CIE XYZ to CIE Luv
convert CIE Luv to CIE LCHuv
get average differences for each component in CIE LCHuv
plot results
```

All colour transformations were performed using the built-in functions of the open-source *colour* library (Colour Developers, 2022). For colour conversion from RGB values to CIE XYZ, a conversion matrix was used that takes into account CIE xy chromaticity coordinates of a reference light source and Bradford chromatic adaptation. The conversion matrix is shown in Equation 1 (Lindbloom, 2022).

$$RGB\_to\_XYZ = [[0.4360747, 0.3850649, 0.1430804], [0.2225045, 0.7168786, 0.0606169], [0.0139322, 0.0971045, 0.7141733]] \quad (1)$$

No additional parameters were required to convert CIE XYZ to CIE Lab, CIE Luv and CIE LCH_{uv}. The CIE Lab values were needed for the calculation of colour differences, while CIE Luv was necessary for CIE LCH_{uv} calculations. The colour differences were calculated according to the Delta E (CIE 2000):

$$\Delta E_{00} = \sqrt{(\Delta L'/(K_L S_L))^2 + (\Delta C'/(K_C S_C))^2 + (\Delta H'(K_H S_H))^2 + R_T (\Delta C'/(K_C S_C)) (\Delta H'/(K_H S_H))} \quad (2)$$

where *ΔL′, ΔC′, and ΔH′* are differences of the two observed colours for lightness, chroma and hue, S_L, S_C, and S_H are compensations for lightness, chroma and hue, k_l, k_c, and k_h are parametric weighting factors set to unity ($k_l = k_c = k_h = 1$), and R_T is a hue rotation term.

The colour differences were calculated twice. First, we calculated ΔE_{00} for test images and measured the colour values of the patches, and then we used the image of a test chart taken in the darkroom as a reference image and compared images from other environments with it. We chose to use this correlation in the second part of the study because the objective of this study is not only to evaluate the influence of the surrounding space on the lighting conditions of the photographic scene and to determine the appropriate variations of the environment to achieve optimal results, but also to evaluate our laboratory conditions, i.e., the darkroom, in comparison with other possibilities.

2.3 Colour properties

Since it was expected that the major surfaces in the test environments would affect the lighting conditions in the observed scene, their colour properties were described.

We measured the degree of reflected light from the black wall in the darkroom, five coloured backgrounds, two reflective surfaces, and both sides of the light-shaping attachments (front and back) using a *Zehnter Gloss ZGM 1022* glossmeter at an angle of 75°, as this is the standard angle for paper materials. Three measurements were taken for each material, changing position and material orientation to eliminate the influence of fibre direction where appropriate. The results for surface reflectance are shown in *Figure 3*.

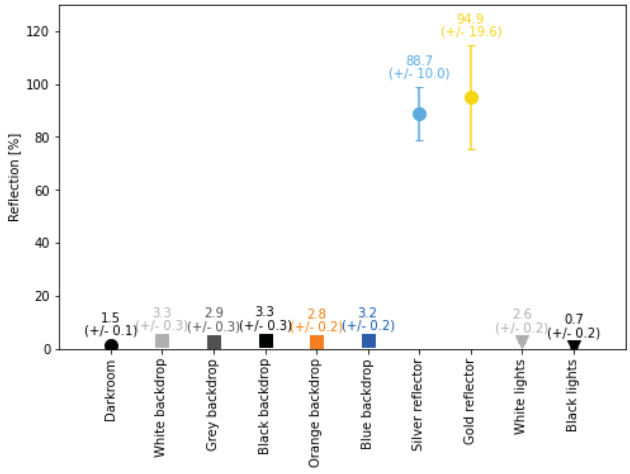

Figure 3: Surface reflection of key materials in the scenes.

We measured the CIE XYZ values of these key surfaces using the *X-Rite i1 Pro* spectrophotometer in reflectance mode and *Argyll* software and plotted them in *Figure 4* in CIE xyY colour space. Each colour patch on the *ColorChecker DC* was measured using the Argyll *spotread* function, returning CIE XYZ values. To determine the colour characteristics of the observed scene, we used the *X-Rite i1 Pro* in emission mode. The spectrophotometer was placed in the centre of the *ColorChecker DC* test chart with the measurement head pointed at a grey ceiling and not directly at the light source or reflective surfaces. Light source emission was measured with the same setting, while the instrument was directed into the light source. All measured CIE xyY values are shown in *Figure 4*, along with spectral power distribution plot.

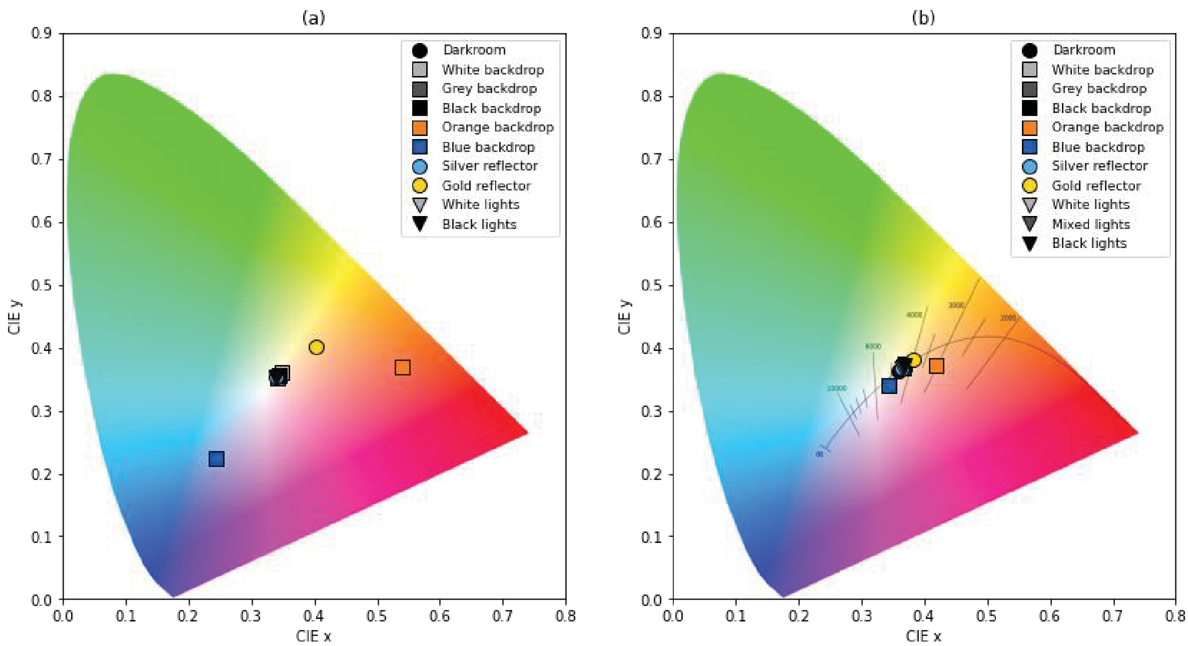

Figure 4 (part 1): Colorimetric data in CIE xy colour space for (a) main surfaces in test environments, and (b) light properties at the scene. (c) shows CIE Y lightness data from the CIE xyY colour space for main surfaces in test environments (material), and light properties at the scene. Plot (d) shows the emission spectra of light source.

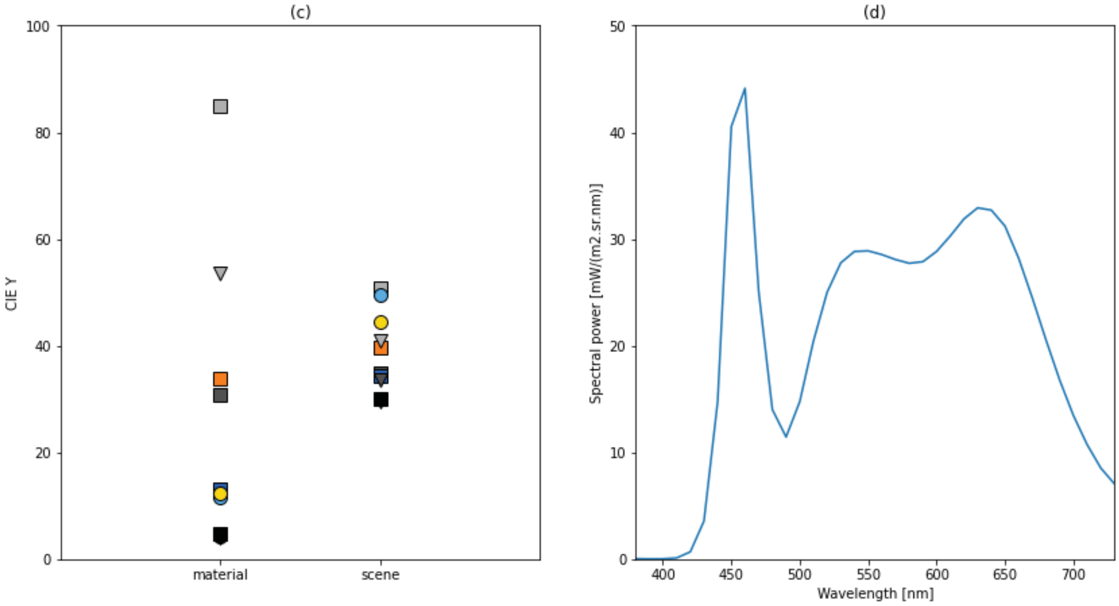

Figure 4 (part 2): Colorimetric data in CIE xy colour space for (a) main surfaces in test environments, and (b) light properties at the scene. (c) shows CIE Y lightness data from the CIE xyY colour space for main surfaces in test environments (material), and light properties at the scene. Plot (d) shows the emission spectra of light source.

3. RESULTS AND DISCUSSION

The ΔE_{00} colour differences were first calculated for all 240 colour patches on the test chart, using the measured colour values of the patches as a reference. The average values for the entire test chart are shown in *Figure 5*, together with the standard deviation within the sample.

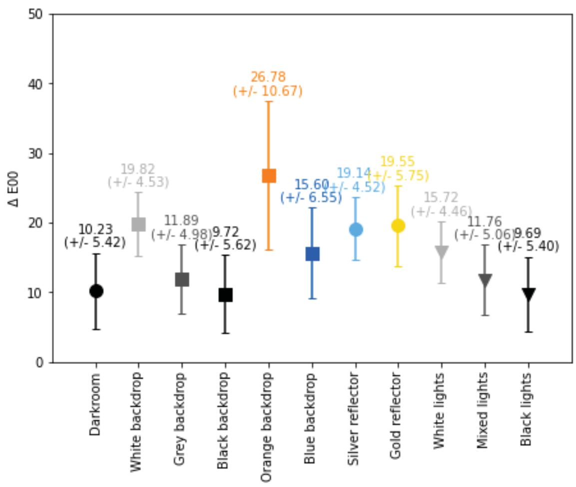

Figure 5: Mean colour difference ΔE_{00} with standard deviation of the sample between measured colour values of the ColorChecker DC and tested setups.

The results in *Figure 5* show that the lighting conditions in the scene change drastically when the background is changed. In darker environments such as darkroom, grey and black backdrops, and grey and black lights, the colour differences are the smallest, indicating the best colour rendering conditions. This is due to the combination of: (1) low surface reflectance of the materials (0.7% for black lights, 1.5% for darkroom, 2.9% for grey, and 3.3% for black background), (2) their CIE xy values are near the white point and have no obvious chromaticity, and (3) the brightness values are relatively low compared to other samples, except for the grey background (3.99 for black lights, 4.36 for darkroom, 30.82 for grey, and 4.86 for black background). We expected the white background and white lights to give similar results, but they show a higher colour difference (19.82 and 15.72, respectively), although their

reflectance rates (3.3% and 2.6%, respectively) are in the same range as the darker backgrounds and show no obvious material chromaticity. However, their CIE Y values are the highest of the entire test group (84.91 for white backdrop and 53.46 for white lights). This indicates that the brightness of the background material is a sufficient parameter to affect the colour differences that appear in the photographic scene, but there is a threshold in the brightness of the material affecting the scene, as a grey backdrop does not produce the colour differences to the same extent. This finding prompted us to analyse the brightness and colour properties separately in the further course of the study.
Based on the data in *Figure 4(a)* and *(b),* we would expect the blue and orange backdrops, along with the gold reflector, to produce the greatest colour differences, as a colour shift is clearly seen on a scene when comparing plot *(a)* with plot *(b)*. The corresponding colour differences in *Figure 5* do have higher ΔE_{00} values: 15.60 for the blue background, 19.55 for the gold reflector, and 26.78 for the orange background. However, the silver reflector has a ΔE_{00} value of 19.14, although it shows no obvious effect on the colour shift when comparing plots *(a)* and *(b)* in *Figure 4* and has a relatively low CIE Y value as a material (11.68). This suggests that the ability of the material to reflect light can strongly influence the colour differences produced in a photographic scene. Not only the chromatic properties of the gold reflector can be the reason for the change in the properties of the scene, but also its reflections since the brightness CIE Y is similar to the silver reflector (12.32). The gold reflector reflects an average of 94.9% of the light, with a standard deviation between the three samples of 19.6%, while the silver reflector reflects an average of 88.7%, with a deviation of 10.0% between the samples. These measurements indicate a high degree of optical non-uniformity of the surface, making the material unpredictable in reflecting light on the observed scene.
To further investigate the influence of background brightness, chromaticity, and reflectance on the photographic scene properties, we converted the results to the CIE LCH_{uv} colour space, which gives us more detailed information about the brightness, chromaticity, and hue changes. The differences between the average values of 240 colour patches of each scene and the measured reference values are shown in *Figure 6(a)*, separately for each of the three components *ΔCIE L* for the difference in brightness, *ΔCIE C* for the difference in colour, and Δ *CIE* H_{ab} for the difference in hue. Since results have different ranges (from 0 to 100 for *Δ CIE L* and *Δ CIE C*, and from 0 to 360 for Δ *CIE* H_{ab}), they were normalised to illustrate the influence of backgrounds on each of the three colour components. The normalised values are shown in *Table 1* and *Figure 6(b).*

Table 1:Normalized values Differences for each component in CIE H_{ab} *colour space between measured colour values of the ColorChecker DC and tested setups.*

Sample	Dark-room	Backdrops					Reflectors		Lights		
		White	Grey	Black	Orange	Blue	Silver	Gold	White	Mixed	Black
Δ CIE L	0.199	0.529	0.276	0.179	0.803	0.058	0.489	0.572	0.404	0.259	0.190
Δ CIE C	0.024	0.182	0.065	0.002	0.416	0.940	0.222	0.360	0.163	0.045	0.002
Δ CIE H_{ab}	0.069	0.162	0.090	0.063	0.245	0.021	0.153	0.185	0.127	0.085	0.066

In *Figure 6(a)* and *(b)*, we see similar trends in the results as in *Figure 5*, with the curves changing drastically and splitting in the blue background arrangement. In this case, the ratio between the components affected by the scene adjustment is the largest, as the chromaticity is changed the most (0.94), while the change in brightness and hue is close to 0 (-0.06 and -0.02, respectively). This leads to the conclusion that even materials that are neither very bright nor extremely reflective can influence the colour situation of the scene only due to their chromatic properties. In this particular case, however, we expect this result to be a consequence of the blue colour of the material surface, which corresponds to the region where the light source radiates with the highest intensity. This can be seen in the emission spectra (*Figure 4(d)*). Therefore, we expect the material to absorb most of the illuminating light, resulting in less reflected light and consequently less influence on the colour differences of the scene.
For all other setups, the brightness difference *Δ CIE L* is most affected out of the three parameters and becomes proportionally larger with background brightness. This is evident when comparing the *Δ CIE L* results for black (0.18), grey (0.28), and white backgrounds (0.53) with their CIE Y values of 4.86, 30.82, and 84.91, respectively. The difference between chromaticity and hue for grayscale background situations (backgrounds and lights) is at least half that of brightness and never exceeds 0.2, indicating that

the light reflected from the background does not contain any additional chromaticity not generated by the light source. However, once any type of chromatic surface is present, this drastically changes the properties of the scene. For coloured samples (orange and blue backdrop, silver and gold reflector), not only the *Δ CIE C* chromaticity values are the highest, but also the *Δ CIE* H_{ab}, indicating a shift in hue, the *Δ CIE* H_{ab} for blue backdrop deviating from this thesis only due to illumination conditions.

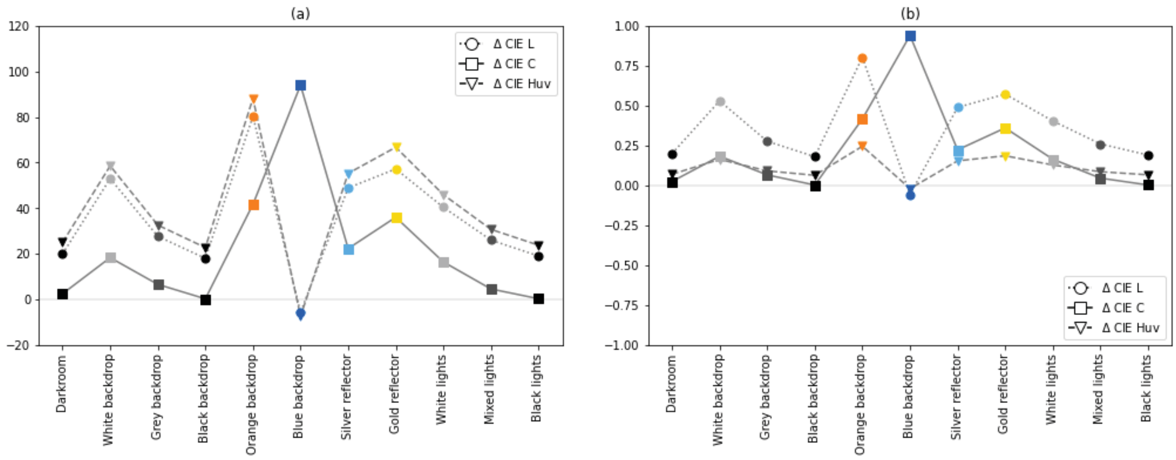

Figure 6: Differences for each component in CIE H_{ab} *colour space between measured colour values of the ColorChecker DC and tested setups (a) in their original values and (b) normalized values.*

Results for the darkroom setup show low ΔE_{00} values (10.23), along with the black backdrop (9.72) and black light (9.69). All three samples are closely followed by grey backdrop (11.89) and mixed lights (11.76). These five setups also produce the lowest chromaticity and hue differences, while darkroom, black backdrop, and black lights have low *Δ CIE L* values, ranging from 0.179 to 0.199. Therefore, we evaluate the darkroom, black backdrop and black lights setups as the most successful in having no effect on the colour properties of the scene and suggest that such setups should also be used in research analysing the colour properties of scene elements.

To further determine the usefulness of our darkroom laboratory, we calculated ΔE_{00} between the setups and the reference values, this time using the darkroom results as reference. The results are shown in *Figure 7* and show the largest deviations for coloured and bright setups.

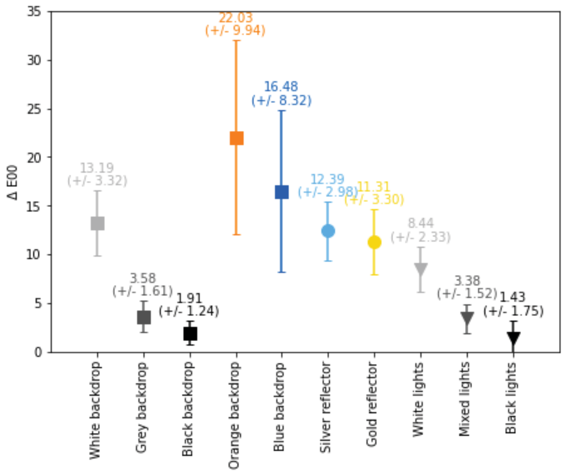

Figure 7: Mean colour difference ΔE_{00} *with standard deviation of the sample between darkroom image and images of other setups.*

According to Mokrzycki & Tatol (2011), a colour difference that is not perceptible to the human eye has a ΔE_{00} value of less than 5, so the black backdrop, grey backdrop, black lights, and mixed lights setups are suitable substitutes for our laboratory darkroom. However, we would like to point out that the experimental setups in this study were small, illuminated with one light source, and set up to determine the influence of a single key area. In setups with multiple light sources, the light moves in different directions and can be reflected not only from the background but also from the sides of the photographic scene. In this case, the studio setups would only be applicable if all sides had the same surface properties and were equidistant from the subject. The darkroom laboratory involved in this research makes these conditions possible and is therefore our choice for further research.

4. CONCLUSION

Research has shown that surfaces in the environment should have the lowest possible reflectance, no obvious coloration, and low brightness values so that the photographic scene is affected as little as possible by the environment. Each of these three parameters has been shown to have a significant effect on the observed colour properties of the scene.
We have observed a large influence of the properties of the light source on the colour conditions of the scene in cases where the emission spectrum of the light source overlaps with the reflection spectrum of the material under study, resulting in the majority of the light being absorbed and therefore the background having less influence on the illumination differences of the scene.
We recommend the use of a special environment for any photographic examination that includes colour analysis. Surfaces in this environment should be grayscale and low brightness, preferably grey or black, with a low reflectance. In order to design more specific and numerical guidelines, a more extensive research should be conducted that defines an acceptable threshold for the brightness and reflectance of the surfaces.

5. ACKNOWLEDGEMENTS

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