Guidelines on test methods for visual evaluation of goniochromatic samples

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Abstract	:	Aim of the WP 5 is to measure the visual attributes of materials through subjective responses, providing a connection between the visual appearance, evaluation and metrological characterisation of a material. The visual attributes, gloss, goniochromatism etc. can be easily recognised, categorised and scaled by subjects. Whilst some of these appearances have a traditional metrological definition, new material appearances are not well described in metrological terms, or even by subjective perception. In this report, based on INRIM and UA findings, we propose in a schematic way a guideline for the visual evaluation of goniochomatic samples.
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In the EMRP Joint Research Project (JRP) "Multidimensional Reflectometry for industry", the following partners cooperate to validate *reliable optical measurements with traceability to SI system to describe the overall appearances of modern surfaces: LE-CNAM (Coordinator), PTB, CSIC, INRIM, MIKES, CMI, Innventia, Katholieke Universitet Leuven, Universitat d'Alcant, and Callaghan Innovation. See http://www.xdreflect.eu/ for more information.*

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SUMMARY

This deliverable is a guidelines for the arrangements of visual experiments in goniochromatic visual experiments, based on the findings of D5.2.4, D5.3.2, D5.41, D5.4.2. The suggestions are about: geometry of illuminaion and observations, lighting conditions and their influences on the perceived qualities.

1 INTRODUCTION

The appearance of a product is important for EU economy: industrial artefacts are evaluated by their appearance, especially automotive, cosmetics, packaging and plastics products: appearance is one of the most critical parameters affecting customers choice. CIE is working [6] on the definition and measurement of Appearance, but a mathematical modelization of Total Appearance is still far from being defined for several reasons [7], mainly: complexity, available knowledge on the quantities defining appearance and measurement methods and accuracies. Measuring the total appearance of an object or of a scene, is a very complex exercise [9], so one suggested approach is to study the appearance for simplified conditions, investigating the perceived attributes defining artefact, conditions of observation and illumination and materials characteristics [7].

Materials characterization, related to light interaction, is implemented using methods, quantities and measurements conditions initially defined for CRM (Certified Reference Materials,e.g. ceramic or glass tiles) for units maintenance and dissemination that are not representative of industrial artefacts, but useful for applications related to production tolerances or device calibration, but useless for appearance prediction because conditions of observation (including geometry and spectral behaviour of lighting, geometry and viewing conditions) are very far from reference materials, as also the conditions of measurements from the real condition of perception. The result is that CRM do not provide adequate references for applications related to the analysis of perceived qualities, also because a full understanding of appearance is very far from being understood.
INRIM performed several visual experiments in order to test different appearance qualities of goniochromatic materials, considering attributes like: sparkling, graininess and brightness. The suggestions provided in this guideline are based on the results of D5.2.4, D5.3.2, D5.41, D5.4.2 .
Even if the commitment with Euramet of INRIM was to test only on D5.4.1 the influences of SSL and not SSL sources, the results achieved pushed to do deeper investigations on appearance evaluation of different perceived qualities in presence of SSL and not SSL lighting sources as contribution to researches on SSL appearance influences.

1.1 Measurement geometries for goniochromism and sparkle

Typical color-measuring instruments based on an optical device named integrating sphere for providing diffuse light incident over panel surface are not recommended for gonio-apparent colors taking into account some international standards and procedures [3] [5]. So, the right basic optical design for measuring color is shown in Fig. 1

According to CIE notation in Fig. 1 the measurement geometry is 60ºx:105º. But, following guidelines of ASTM/DIN normatives, more practical for the automotive industry, this same measurement

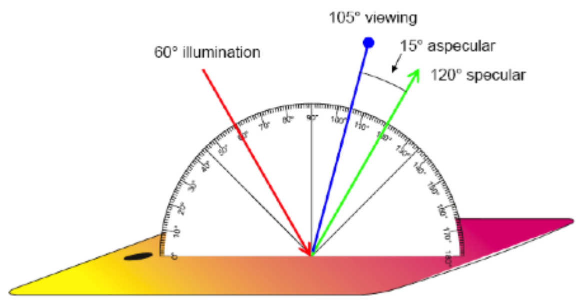


Figure 1: Schema of the illumination (influx) and observation (detection or efflux) angles used in this report following the CIE ASTM/DIN terminologies

geometry would be 30as+15, taking into account the angle deviation, or aspecular angle, for observation/detection from the specular direction and the zero scale from the normal to the surface. Nowadays, the main influx or incident angle is 45º, Fig. 2 and it is the selected one by ASTM and DIN normatives [4] [3] recommending procedures to characterize gonio-apparent colors.

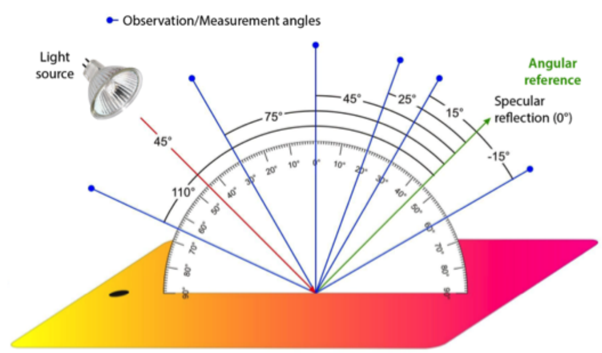


Figure 2: Schema of the illumination (influx) and observation (detection or efflux) angles used in standards for automotive coatings.

Many of these new gonio-apparent coatings and plastics have new visual effects due to some micro-textures proposed by ASTM E284-13b normative, named sparkle or glitter (viewed under directional illumination), or graininess or coarseness (viewed under diffuse illumination). However, only one instrument, the BYK-mac, also running as multi-angle-spectrophotometer, currently incorporates a basic optical design Fig. 3 for measuring the sparkle and graininess effects. Therefore, for the final visual approval of gonio-apparent materials in car bodies, it is necessary to match both colour and texture in some visual directions and textures.

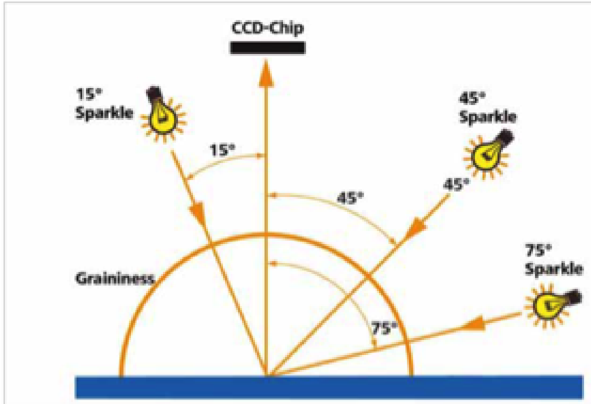


Figure 3: Basic optical design for measuring the sparkle (or glitter) effect in the BYK-mac multi-angle-spectrophotometer. With diffuse illumination configuration, this instrument also measures the texture effect named graininess (or coarseness)..

2 Testing methodologies

2.1 Lighting booths

In many industrial applications where color matching and visual approval is related to solid or homogenous colors it is usual to work with diffuse lighting booths [2] [1]. In the automotive sector, and in special for interior trim, or for visual assessments of curved components based on solid pigments, the most used lighting booths have diffuse illumination. Commercial lighting booth usually have a list of fluorescent Fig. 4 and incandescent lamps or LED for simulating with different grades of colorimetric performance some CIE standard illuminants as D65, A, F11, etc.

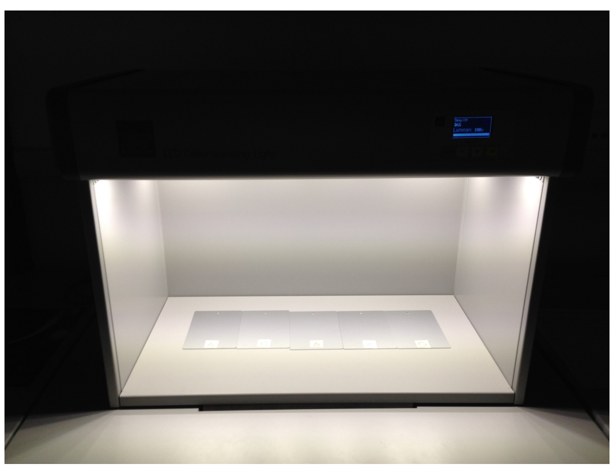


Figure 4: Commercial lighting booth with diffuse lighting and goniochromatic samples on the observation plane

But, for gonio-apparent panels, trying to perceive all their color travel, or lightness and color flops, it is recommended to use a directional lighting booth, and preferably with an opto-mechanical designfor the viewing area or plane following the guidelines of some international standards. In this case, the best example of commercial directional lighting booth is the byko-spectra effect (BSE) by BYK-Gardner. Moreover, this new lighting booth also has additional luminaires for visual evaluation of sparkle for the three recommended geometries asin Fig.3. Other interesting lighting booth for gonio-apparent colors, but not useful for color discrimination and its visual tolerances, is the gonio-vision-box (http://www.goniovision.com/ , GVB), which partially enables to percept the color gamut of gonio-apparent panels for the most of multi-angle spectrophotometers. However, recent results from the GVC-UA [8] have shown that the color gamut of many gonio-apparent panels can be very large, and now it can be visualized by a new palette or gamut brochure from multi-angle spectrophotometric data.

Lighting booth can be realized also ad hoc for special needs and purposes Fig.5 especially regarding the choice of lighting source: in the lighting booth of Fig.5 Commercial compact fluorescent and LED sources are used.

Figure 5: Ad hoc built lighting booth at INRIM to test goniochromatic materials with goniochromatic samples on the observation plane

3 Findings about Lighting booths

Since all multi-angle spectrophotometers apply computationally or virtual the D65 illuminant for colorimetric calculations in every measurement geometry, it is essential to check whether the spectral power distributions of the lamps inside a lighting booth have a good spectral correlation with D65, or other CIE illuminants (F11, A, etc). This test or spectral characterization can be easily done by a tele-spectroradiometer, and its corresponding white reference inside the lighting booth. Using therefore the white reference it is very easy to measure the spectral power distribution (SPD) of any light source or luminaire of each lighting booth, and transforming the spectral data into colorimetric data and other typical colorimetric parameters in order to evaluate the color quality of any light sources and illuminants Fig. 6

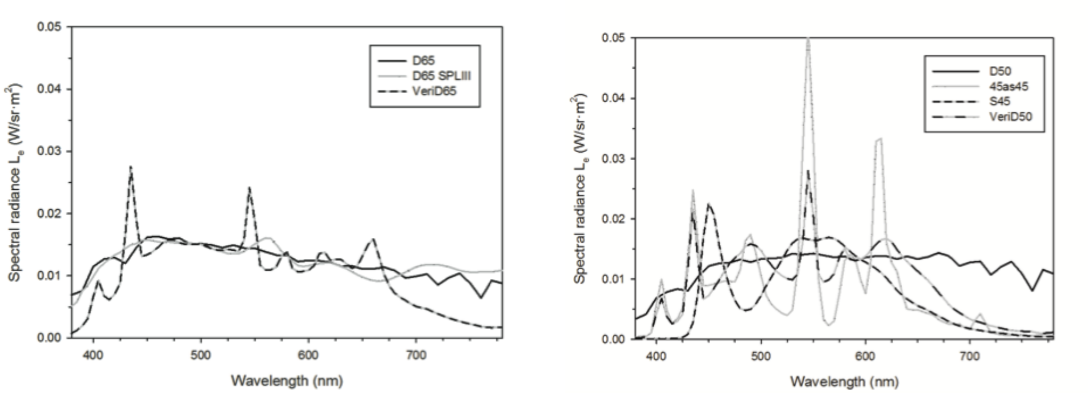


Figure 6: Absolute SPD (spectral radiance), normalized to 1000 lx of illuminance level, of the light sources installed in the lighting booths analyzed in this report. Left: D65 illuminant (as reference), SpectraLight III and Verivide D65 simulators. Right: D50 illuminant (as reference), byko-spectra effect (45as45, for color evaluation, and S45, for sparkle, luminaires) and Verivide D50 simulator.

The lighting booths must be also photometrically characterized, to verify illuminance on the sample plane, Fig.7

3.1 ad hoc lighting booth

Considering the ad hoc built lighting booth it is possible to chose luminous sources and arrange them in order to achieve the desired illuminance level on the sample plane as well setting up the desired geometrical conditions of illumination and lighting Fig. 9

Using commercial lighting source requires anyway the full spectral characterisation of the spectral distribution of the lighting source inside the booth in order to take in account of the wall influences Fig. 10and of discrepancies between declared data and measured data. Fig. 11

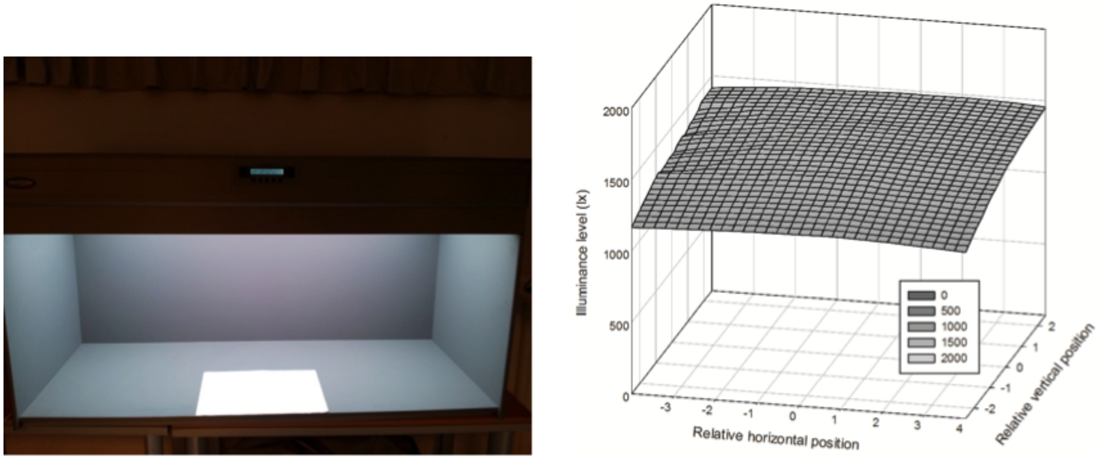


Figure 7: Illuminance field (left: picture; right: 3D mesh) of the Verivide CAC-150-5 with the D65 simulator. Absolute scale: Δx = Δy = 5 cm.

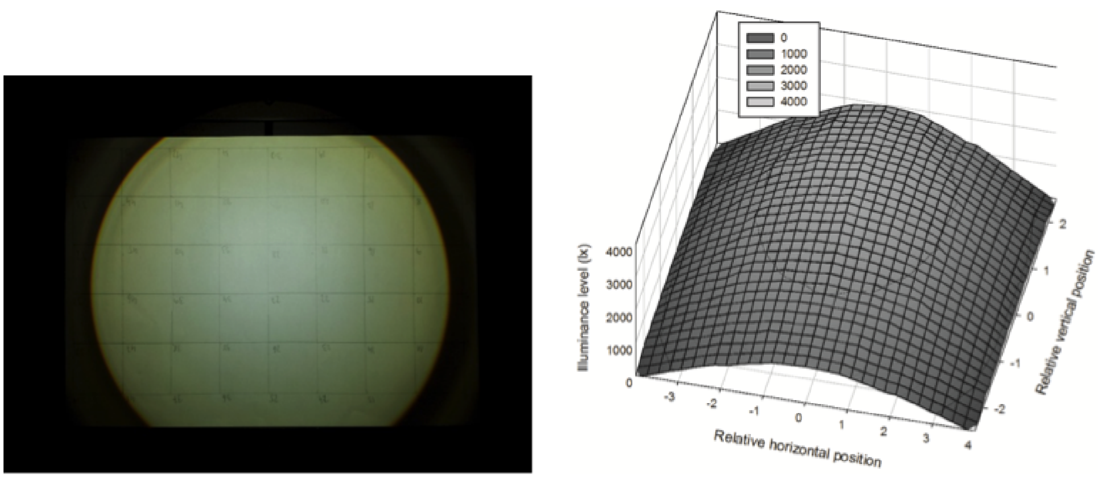


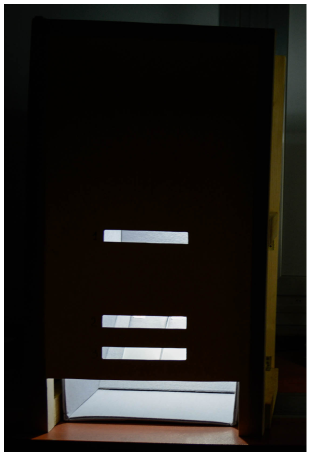
Figure 8: Illuminance field (left: picture; right: 3D mesh) of the byko-spectra effect cabinet for the measurement geometry 45as45 (color evaluation, top) and S15 (sparkle evaluation, bottom). Absolute scale: Δx = Δy = 5 cm.

4 Findings on lighting booths

Consequently, from these spectral and colorimetric and photometric data we can conclude that:

- The commercial diffuse lighting booths, as those offered by Verivide and X-Rite companies, have the maximum spectral and colorimetric quality indexes for reproducing the D65 standard illuminant;

- The commercialdirectional lighting booth, named byko-spectra effect (BSE), uses a D50 simu-



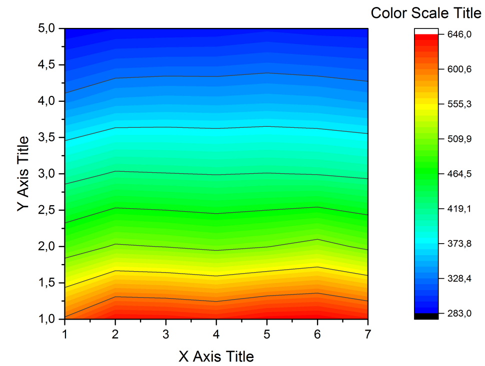


Figure 9: Ad hoc lighting booth with compact fluorescent tube: left: picture the lighting booth with three observation direction (as in Fig. 2 i.e. 0°, 20°, 30° from the normal) right: illuminance map

Lighting characteristic		Cool White Sources	
		CW-LED	Compact-Fluorescent Lamp
CCT [K]	Declared	4000	4200
	Measured	3990	3875
R_a	Declared	80	-
	Measured	85	87
R1	Light greyish red	83	92
R2	Dark greyish yellow	90	98
R3	Strong yellow green	93	58
R4	Moderate yellowish green	82	90
R5	Light bluish green	83	96
R6	Light blue	85	88
R7	Light violet	89	92
R8	Light reddish purple	72	86
R9	Strong red	29	45
R10	Strong yellow	75	64
R11	Strong green	80	86
R12	Strong blue	61	70
R13	Human complexion	85	91
R14	Leaf green	96	71
R15	Japanese skin	80	91

Figure 10: Ad hoc built lighting booth at INRIM comparison between measured and declared data for cool white sources: LED and compact fluorescent source

lator (for the 45as45 geometry and the rest of five geometries, Figure 5, bottom) with good level of spectral and colorimetric performance for reproducing the D50 standard illuminant, but not faithfully the D65 illuminant. (The X-Rite SpectraLight III has not a D50 simulator based on a fluorescent lamp, but it is possible for the new SpectraLight QC Light Booth.)

- Knowing above other advantages for the byko-spectra effect related to goniochromism, and

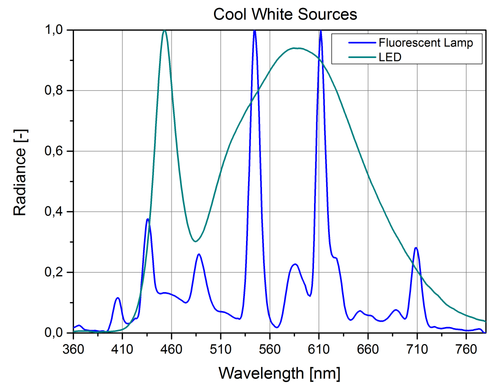


Figure 11: Ad hoc built lighting booth at INRIM measured spectral distribution of cool white sources: LED and compact fluorescent source

searching to improve the visual and instrumental correlation between a multi-angle spectrophotometer (BYK-mac or X-Rite MA98) and a directional lighting booth, it is recommended to select D50 (noon sky daylight) as illuminant for instrumental data.

- Unfortunately, and as second option but not applicable till now, there is not an excellent D65 simulator based on fluorescent lamp, and with the same size and ballast than that installed currently (Philips Master PL L 90 De Luxe 55W/950/4P) into the byko-spectra effect. Maybe in future, some multinational lighting companies as Philips or Osram can provide an excellent D65 simulator to be installed into the byko-spectra effect.

- The most uniform illuminance field belongs to a diffuse lighting booth (illuminance average > 1400 lx), but it has as main drawback that it is not useful for color evaluation for many directional viewing and well correlated with a multi-angle spectrophotometer

- In case of using a directional lighting booth, as byko-spectra effect, it is advisable to put horizontally the panels (Figure 10) for working at illluminance levels over 1400 lx, both for color and sparkle evaluations, and whenever possible to select previously instrumental data under D50 illuminant, or evaluate the influence on the visual and instrumental correlation due to this small gap between D50 and D65

- For ad hoc built lighting booth it is necessary to verify the actual radiation inside the booth: the declared values of commercial lamps are not sufficient, as well the uniformity of illuminance must be verified for the condition of incidence radiation

5 Findings about influences of experiments set-up

In order to provide a guideline on the visual evaluation of goniochromatic samples it is necessary to consider two different approaches in subjective experiments set-up:

- subjective experience with a fixed direction of view, i.e. a fixed direction of view respect to the normal to the samples surface;
- subjective experiences without a fixed direction of observation, i.e. the subjects are free to perceive the samples in open condition, without restriction in the field of view.
- the source used in the experiment considering its spectral distribution and not the CCT (Correlated Colour Temperature)

The following table summarizes the findings of different subjective experiments and provides a guideline for future evaluations.

Condition of observation	Suggestions about geometry		Lighting Source		Considerations about investigation on sparkle	Considerations about investigations on graininess	Consideration about Brightness
	Direction of illumination	Direction of observation	Source type	CCT			
Fixed	Direct: 1) preferrable to choose the same direction of instrument for characterization; 2) preferrable to choose a condition close to the application under investigation	Direct: Better to avoid direction close to specular reflection: 1)the direction of observation should be farer than 15° from the specular direction 2) preferable to choose a condition of observation close to the application under investigation	SSL	Colder CCT enhance the sparkle and graininess perception (e.g. in SSL a source of 4000K is already considere cold white for its blue content), as well brightness and saturation	Improve the perception of sparkle Enhance the JND between samples	N.A.	
			not SSL	N. A.	Presents an higher occurrence of equivalence in the perceived attributes		improve the perception of brightness
	Diffuse for graininess evaluation		SSL	Colder CCT enhance the sparkle and graininess perception (e.g. in SSL a source of 4000K is already considere cold white for its blue content)		Improve the perception of graininess Enhance the JND between samples	
			not SSL	Colder CCT enhance the sparkle and graininess perception as well brightness.			
Open, Subjects are free to observ the condition without restriction on the direction of observation	Direct: 1) preferrable to choose the same direction of instrument for characterization; 2) preferrable to choose a condition close to the application under investigation	Open: Subjects are free to observ the condition without restriction on the direction of observation	SSL	Colder CCT enhance the sparkle and graininess perception (e.g. in SSL a source of 4000K is already considere cold white for its blue content)	Presents an higher occurrence of equivalence in the perceived attributes due to the free condition of observation, with not SSL the occurence of equivalence in the perceived quality evaluation is higher		Presents an higher occurrence of equivalence in the perceived attributes due to the free condition of observation
			not SSL	The brigheness perception is enhanced with colder not SSL sources			Presents an higher occurrence of equivalence in the perceived attributes due to the free condition of observation, with not SSL the occurence of equivalence in the perceived quality evaluation is higher, Improve the brightness perception
	Diffuse for graininess evaluation		SSL	Colder CCT enhance the sparkle and graininess perception (e.g. in SSL a source of 4000K is already considere cold white for its blue content)			Presents an higher occurrence of equivalence in the perceived attributes due to the free condition of observation, with not SSL the occurence of equivalence in the perceived quality evaluation is higher
			not SSL	The brigheness perception is enhanced with colder not SSL sources			Presents an higher occurrence of equivalence in the perceived attributes due to the free condition of observation, with not SSL the occurence of equivalence in the perceived quality evaluation is higher, Improve the brightness perception

Figure 12: Suggestions for set up of visual experiments when goniochromatic samples are involved

6 CONCLUSIONS

Nowadays there is not an ideal commercial lighting booth yet. The possibility to build ad hoc lighting booth is very interesting because it allows to test specific sources and condition of observation and lighting. The suggested recommendations of this guidelines to take in account of possible drawbacks are:

- Arrange the color panels at horizontal position.
- Verify illuminance uniformity for all geometries of illumination.
- Remind that the fluorescent lamp in tested directional lighting booth is a good D50 simulator, not an excellent D65 simulator.
- Use a tele-spectroradiometer to verify the actual spectral distribution of light inside the lighting booths.
- Remind that using LED or Fluorescent sources at the same CCT doesn't provide the same results.

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