Chapter 2 Real material texture color management in CAD systems for Spatial Design

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Abstract

Over the past 20 years, the methodology of the spatial designer's work has radically changed. This type of design used to be based primarily on experiential aspects and was drafted exclusively through 2D drawing techniques. The design of geometries, the choice of materials and luminaires, were mainly based on the drafting of drawings, reports and descriptive specifications. The use of CAD systems, first born in the engineering sector, has now spread to interior design too. In today’s design process the use of CAD has become fundamental, for the quantitative and qualitative evaluation of the project and up to its final presentation. The new Lighting CAD systems pay special attention to the physical correctness of the light-matter interaction calculation. While luminaire manufacturers have been making standardized photometric data available in online catalogs for a few years now, color information related to interior design materials, coatings and paints, does not follow any standard and uses very different color samples. This chapter does not present a basic theoretical solution to this problem, but proposes an applied design method for managing the colors of real materials, including textured materials, in Lighting CAD.

Keywords:

Lighting, color, CAD, textures, material, spatial design

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1. Introduction

A Lighting CAD provides design verification tools at the design stage. These make it possible, as a first function, to obtain quantitative information on design parameters such as illuminance, on object surfaces, luminance, from predetermined observer positions, the uniformity index U_0 (CEN, 2011), the glare index UGR (CIE, 2010) and other design parameters provided by the standards for interiors. The method of calculating these parameters is often codified by the standards by means of photometric quantities that do not contain information of a spectral and/or chromatic nature.

In recent years, in addition to quantitative verification, Lighting CADs have also offered qualitative evaluation capabilities that allow us to create photo-realistic renderings to try to assess the appearance of the spatial design before production. The computational methods required to obtain this type of image are much more complex than those provided by the standards, because they should try to simulate the interaction between light and matter described by the equations of the electromagnetic field (Maxwell, 1865). In particular, rendering has become a qualitative assessment tool in the design process, often overrated and, indeed, sometimes misleading. Indeed, commercial CAD systems almost always use calculation engines for a rendering of the biased type, which are not based on physically correct calculations of the light-matter interaction. This produces very beautiful renderings, typical of 3D cinema animations, but with little connection with the reality of the project and this can cause misunderstandings with the client when shifting to the implementation phase of the project.

In commercial Lighting CAD systems, Lightscape and other software (Khodulev and Kopylov, 1996) have begun to use unbiased rendering (Arvo *et al.*, 2001). For luminaires, designers access photometric data, in standard formats, available from online catalogs published by manufacturers. While for materials, Lighting CADs simplify the management of input data, which are not defined through radiometric bidirectional reflectance distribution function (BRDF), impossible to obtain for designers, but with colorimetric data. For homogeneous materials, color charts are available that refer to commercial color atlases from which colorimetric data can often be deduced. For textured materials, widely used in interior design, no colorimetric information is ever available, but only images, often downloaded from the Internet, whose acquisition process is unknown and whose colors have little relation with real materials. The designer always selects textured materials such as woods, stones, tiles and laminates based on direct observation of actual samples available from suppliers and not based on photographs downloaded from the Internet.

2. The color issue

Historically, color has been defined by the three parameters *hue*, *saturation* and *lightness*. Hue and saturation are the two chromatic attributes of color. We can therefore consider color as a composition of three attributes: two chromatic and one related to *lightness* (Hunter and Harold, 1987). Starting from the tristimulus theory (Helmholtz, 1867) and from experiments conducted on human subjects (Wright, 1929; Guild, 1931), in 1931 the International Commission on Illumination (CIE) defined the characteristics of the average human chromatic observer (CIE, 2018). With this definition we obtain a non-biunivocal relationship between light radiations and the tristimulus values XYZ, which are the basis of colorimetry and define an absolute color space. From the tristimulus values we obtain the chromaticity coordinates *xy* that define, in the chromaticity diagram, the hue and saturation variations visible to the human eye. Unfortunately, this diagram is not good for a perceptual evaluation of the differences between colors. That is, equal distances in the diagram do not correspond to equal perceivable color differences (MacAdam, 1942). To try to overcome this problem the CIE has proposed other color spaces, among them the L*a*b* has been widely used in many application areas, because it is based on the principle of opposite colors (Hering, 1964).

In the context of using a Lighting CAD for spatial design, the topic of color management of light and materials, which are the subject of the project, is still largely ignored by software manufacturers. Digital color reproduction on displays was born based on relative RGB color spaces that depend on the color characteristics of the reproduction device and do not guarantee a correct representation of color information on different devices. There are also other digital relative color spaces that are based on the three fundamental dimensions of color, such as HSL, HSV, HSI, and HSB, which are used in some software to make the definition of a color more intuitive, but these are only a transformation of the relative RGB color space (Hughes *et al.*, 2013). In everyday design practice, digital color is almost always defined and reproduced in terms of RGB triplets, regardless of the displays and input devices used, with the result that correct color reproduction cannot be guaranteed on different display devices.

However, the problem is even more complex because the correct digital reproduction of real colors is a field of research still open worldwide, to which the international standards, based on colorimetry, although modified over the years (CIE, 2018), are not able to fully respond (Rizzi, 2021). This problem also depends on the fact that color is the psychological-perceptual result of the response of the human visual system to external stimuli, the electromagnetic radiation between 380-780nm, but also to the observation of color in the context of other colors, the history of what has been observed and the development/cultural context of people. In this sense, color is not an objective physical quantity but a subjective qualitative aspect of human visual perception. This definition contrasts with the need to be able to measure, quantify and digitally reproduce color (Land, 1977).

3. Transformations between digital color spaces

Using a Lighting CAD involves managing color information in different relative color spaces. One possible answer to this problem is to use the ICC color profiles of the devices concerned (ICC, 2020). Using this standard, the color information of digital images is managed in a reference format called PCS, instead of the relative RGB color spaces. This mean that the color information contained in the images is managed in an absolute color space, the PCS, which is independent of input/output devices. Two possible PCSs can be used in the ICCv4 standard: the absolute color spaces XYZ, or L*a*b* (ISO, 2010).

Through the ICC profile of an input/output device, the software can transform the color from the absolute PCS color space to the relative color space of the device and/or vice versa. Although it has many limitations, this method makes it possible to maintain color information between devices that have different relative color spaces. The ICC color profile can be created via a calibration procedure for output devices, such as displays and printers, as well as for input devices, such as cameras and scanners. Some manufacturers provide, along with the installation drivers of the device, ICC profiles for their products; these are files with the extension .icc or .icm. However, with the normal aging of the hardware, these profiles quickly lose their validity and must be recreated through a device calibration procedure that can be performed with special measuring instruments.

The XYZ and L*a*b* absolute color spaces attempt to describe the colors that can be perceived by the human visual system and therefore contain a very wide range of colors, which is beyond the color acquisition and reproduction capabilities of commercially available devices. With the advent of the Internet and color monitors, an absolute digital color space, sRGB (IEC, 1999), has been proposed, which display manufacturers should strive to adopt. This color space defines:

A. The chromaticity coordinates of the three RGB primary colors that compliant displays must have.
B. The mathematical transformation of colors between the XYZ and the sRGB color spaces.
C. The reference white, defined by the illuminant D65 standard.
D. The gamma correction ≈ 2.2.
E. The conditions for viewing images on the display. These have 4 requirements:
    1. the average luminance of the display should be ≈ 80cd/m2;
    2. the average reflectance of surfaces adjacent to the monitor should be ≈ 0.2 (preferably gray);
    3. the display should be anti-reflective and have black screens that mask direct light from above and from the sides;
    4. the ambient light where the display is located should have a color temperature of ≈ 5000K.

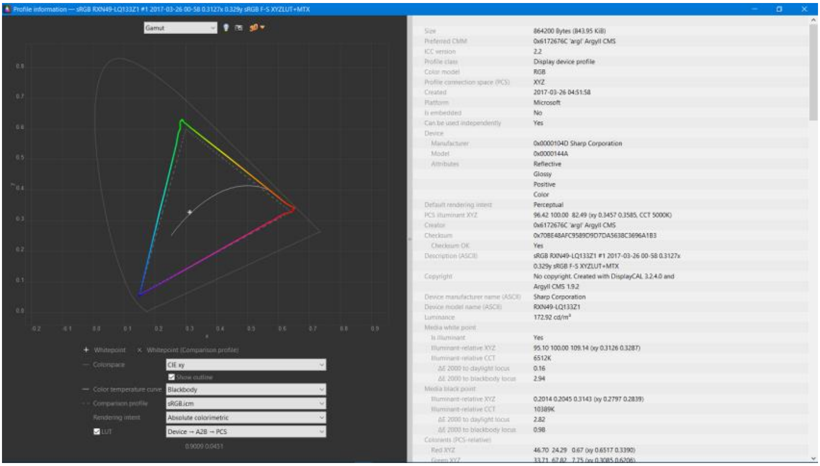
Fig 1 An sRGB monitor set up at a workstation.

Indeed, even right out of the factory, practically no sRGB-compliant display meets this requirement 100%, so it is necessary to perform a color calibration procedure that can be done with a special colorimeter, often called color spider, such as the Datacolor SpyderX® or X-Rite ColorMunky Smile®. This calibration should also be repeated periodically, at least every six months, because during the life cycle of a display it is normal for the characteristics of the product to change as the device ages. The procedure for calibrating a display consists of three steps:

1. The color spider is applied to the display and, following the instructions of the supplied software, or free software such as DisplayCal® (Höch,

2017), the user must adjust the display to conform as closely as possible to the sRGB color space.

2. At the end of the previous step, the software supplied with the color spider provides information on the percentage of compliance with the sRGB standard of the display. It also creates a color profile (.icm or .icc file) of the display, which also depends on the characteristics of the PC graphics card.
3. The color profile that was created in the previous step must be entered in the operating system settings. This will ensure that the application software, equipped with a color management module (CMM), can be informed about the color characteristics of the display.



Profile information — sRGB RXN49-LQ133Z1 #1 2017-03-26 00-58 0.3127x 0.329y sRGB F-S XYZLUT+MTX

Gamut

+ Whitepoint × Whitepoint (Comparison profile)

Colorspace	CIE xy
☑ Show outline	
Color temperature curve	Blackbody
Comparison profile	sRGB.icm
Rendering intent	Absolute colorimetric
☑ LUT	Device → A2B → PCS

0.9009 0.0451

Size	864200 Bytes (843.95 KiB)
Preferred CMM	0x6172676C 'argl' Argyll CMS
ICC version	2.2
Profile class	Display device profile
Color model	RGB
Profile connection space (PCS)	XYZ
Created	2017-03-26 04:51:58
Platform	Microsoft
Is embedded	No
Can be used independently	Yes
Device	
Manufacturer	0x0000104D Sharp Corporation
Model	0x0000144A
Attributes	Reflective Glossy Positive Color
Default rendering intent	Perceptual
PCS illuminant XYZ	96.42 100.00 82.49 (xy 0.3457 0.3585, CCT 5000K)
Creator	0x6172676C 'argl' Argyll CMS
Checksum	0x708E48AFC9589D9D7DA5638C3696A1B3
Checksum OK	Yes
Description (ASCII)	sRGB RXN49-LQ133Z1 #1 2017-03-26 00-58 0.3127x 0.329y sRGB F-S XYZLUT+MTX
Copyright	No copyright. Created with DisplayCAL 3.2.4.0 and Argyll CMS 1.9.2
Device manufacturer name (ASCII)	Sharp Corporation
Device model name (ASCII)	RXN49-LQ133Z1
Luminance	172.92 cd/m²
Media white point	
Is illuminant	Yes
Illuminant-relative XYZ	95.10 100.00 109.14 (xy 0.3126 0.3287)
Illuminant-relative CCT	6512K
ΔE 2000 to daylight locus	0.16
ΔE 2000 to blackbody locus	2.94
Media black point	
Illuminant-relative XYZ	0.2014 0.2045 0.3143 (xy 0.2797 0.2839)
Illuminant-relative CCT	10389K
ΔE 2000 to daylight locus	2.82
ΔE 2000 to blackbody locus	0.98
Colorants (PCS-relative)	
Red XYZ	46.70 24.29 0.67 (xy 0.6517 0.3390)
Green XYZ	33.71 67.82 7.75 (xy 0.3085 0.6206)

Fig 2 Result of the sRGB calibration process of a display viewed in DisplayCal®. The dashed triangle is the sRGB color space. The display has a good quality, as it is 99% compliant with the sRGB color space. Indeed, although the triangle of the display color space is wider than the sRGB one, it does not cover it completely in the red area.

Making the display compliant with the sRGB standard is the first step in ensuring that digital color reproduction is the same on different devices. However, two critical elements remain.

The first is that a slight adjustment of the display brightness, or just the automatic intervention that modern PCs carry out, to change the chromaticity of the display after sunset, so as not to disrupt the human circadian system (Cajochen *et al.*, 2011), is enough to frustrate the sRGB calibration process. The second critical element is that ensuring the color fidelity of digital images between different displays is only the last part of the process, which is not sufficient to ensure that the image on the display is a chromatically reliable representation of reality. The latter part also depends on how the color data is imported from physical to virtual reality and on the calculation model, of the interaction between light and matter, implemented by the CAD software. For example, Autodesk states that some of its software is sRGB-compliant for importing textures and producing renderings.

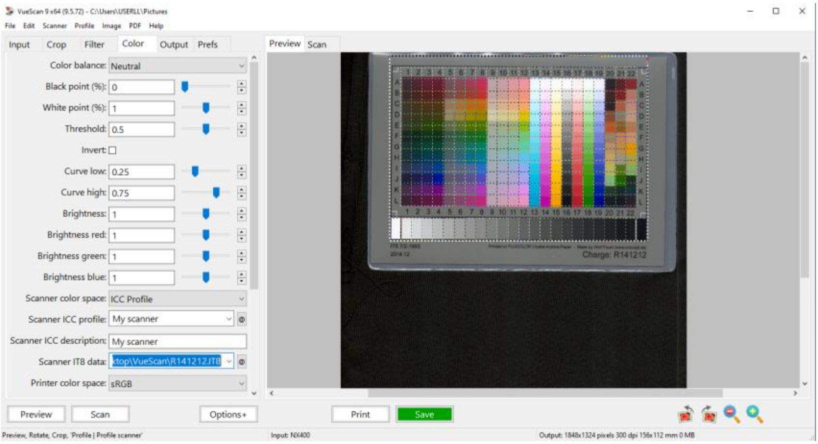
For homogeneous materials a possible solution is to convert the colors of materials measured in the real world from the XYZ color space to the sRGB color space. This type of conversion can be done with matrix calculations that are beyond the scope of this work. For this purpose there are many free software programs (IRO Gr. Ltd., 2020). This approach can be applied only to materials that have a homogeneous color surface; in the case of textured materials a different method is needed.

4. Acquisition of texture colors

In order to incorporate textured materials, such as wood and stone, into Lighting CAD software, images of these materials must be captured with input devices, such as a scanner or camera, which can be calibrated. Downloading images of materials from the Internet or photographing them without an input device calibration process is not sufficient, because we have no guarantee of the color space in which the RGB values contained in the image file, which typically might be in .tif, .jpg or .png format, are defined.

The photography-based method might seem like the easiest method, but it is not (Guarini and Rossi, 2021). Because even if you have a professional camera, a darkroom and lighting systems on a photo set, it is very difficult to ensure uniform illumination on the surface of the material. The most reliable method is based on the use of a scanner, in which the lighting conditions are always carefully controlled.

It is advisable to have an A3 sized scanner to be able to use a larger sample size of material, but an A4 can also be used for this purpose. The scanning software supplied with the scanner should make it possible to calibrate the scanner to produce an .icc color profile of the input device. If not, you can use a third-party software such as, for example, VueScanPro® (Hamrick, 2020). Finally, it is necessary to have a calibration table such as the one defined by the IT8.7/2 standard (ANSI, 2008), which comes with a CD containing the color data from the table. This is printed on special photographic paper that guarantees color reliability for 2 years after its purchase.



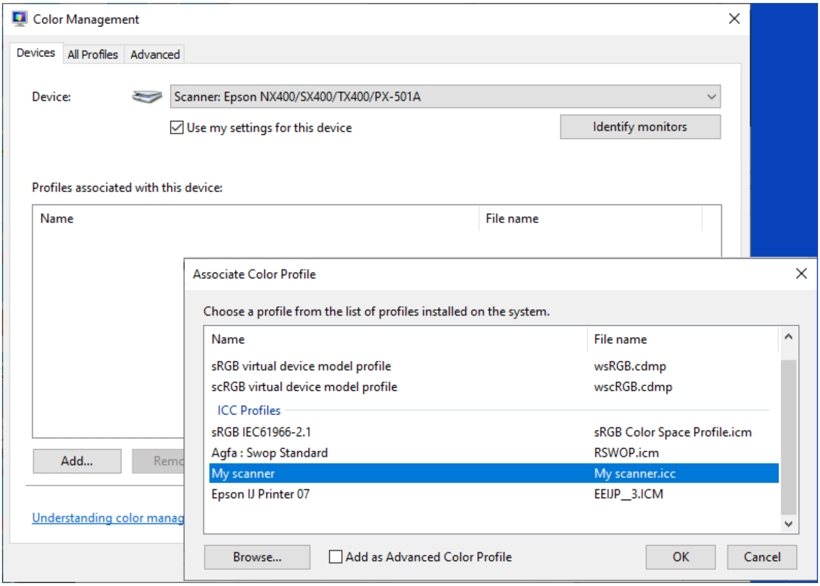
VueScan 9 x64 (9.5.72) - C:\Users\USERLL\Pictures

Color balance: Neutral
Black point (%): 0
White point (%): 1
Threshold: 0.5
Invert: ☐
Curve low: 0.25
Curve high: 0.75
Brightness: 1
Brightness red: 1
Brightness green: 1
Brightness blue: 1
Scanner color space: ICC Profile
Scanner ICC profile: My scanner
Scanner ICC description: My scanner
Scanner IT8 data: ktop\VueScan\R141212.IT8
Printer color space: sRGB

Charge: R141212

Preview, Rotate, Crop, 'Profile | Profile scanner'
Input: NX400
Output: 1848x1324 pixels 300 dpi 156x112 mm 0 MB

Fig 3 Creating the scanner's ICC color profile with the VueScanPro® software and the IT8.7/2 table.



Device: Scanner: Epson NX400/SX400/TX400/PX-501A
☑ Use my settings for this device

Profiles associated with this device:

Name	File name

Choose a profile from the list of profiles installed on the system.

Name	File name
sRGB virtual device model profile	wsRGB.cdmp
scRGB virtual device model profile	wscRGB.cdmp
ICC Profiles	
sRGB IEC61966-2.1	sRGB Color Space Profile.icm
Agfa : Swop Standard	RSWOP.icm
My scanner	My scanner.icc
Epson IJ Printer 07	EEIJP_3.ICM

☐ Add as Advanced Color Profile

Fig 4 The .icc input profile of the scanner, created with the VueScanPro® software, is placed in the Windows10® OS color management settings. With this setting, applications equipped with a CMM can manage the colors of images scanned by the scanner.

The texture acquisition procedure of the chosen material is based on the following five main steps:

1. Calibrating the scanner. This consists of acquiring the IT8 table, using the scanning software set to calibration mode, to create the scanner's input .icc profile (figure 3).
2. The .icc profile created in this way should be placed in the operating system’s settings for the color management of the scanner device, so that applications that use the scanner know its input color characteristics (figure 4).
3. Acquisition of the texture of the chosen material. Through the software of the scanner, in which the .icc profile has been selected, and in scan mode, the image of the material is acquired in RAW format, which saves a greater quantity of chromatic data. Then the image in RAW (.tif container format) is saved. At this stage it is best to capture the material, which will have some thickness, by covering it with a black cloth rather than using the normal scanner cover which would let ambient light through (figure 5).
4. Converting the color of the RAW image from the relative color space of the scanner to the sRGB format using CMM-equipped software, such as Photoshop®. This step consists of 6 secondary steps:
    a. The software’s RGB workspace must be set to the scanner's .icc color profile set in step 2.
    b. In the conversion options of the color settings the relative colorimetric intent should be selected.
    c. The RAW file acquired in step 3 must be opened in Photoshop.
    d. The .icc color profile of the scanner must be assigned to the RAW image.
    e. The color space of the image must be converted to the sRGB IEC61966-2.1 profile
    f. The image must be saved in .tif format with the sRGB profile embedded in the image file. In this way we get a non-RAW .tif file defined in the sRGB absolute color space.
5. A final step is to touch up the sRGB .tif image of the texture to make it seamless.

When a sRGB texture, of a material sample, has to be attributed to a 3D model, almost always it does not have the appropriate size and must necessarily be repeated several times on the surface of the object and may present unrealistic discontinuities (figure 5), for example in the grain of wood and stone. To overcome this problem and make the texture repeatable, we need to make it seamless, i.e. without seams on the four sides of the image.

Fig 5 A solid wood acquired through a scanner. The horizontal and vertical limits of the texture image have been shifted to the center to highlight the discontinuities at the edges. The texture is not seamless.

To obtain a seamless texture a first step is to open the image with a photo editing program and proceed to crop the image so as to obtain an internal part of the sample with square proportions. This will make it much easier to map the texture to the objects in the 3D model, i.e. the process of indicating the correct measurements and proportions of the texture to be applied. To correct the texture, we must use an operator that moves the image within its frame. This will highlight the two horizontal and vertical discontinuity lines of the texture within its frame. Using blurring tools such as stamp and clone, we can retouch discontinuities by sampling nearby areas of the image with similar colors, replacing areas of pixels where the discontinuity is visible with others where it is not, and using a soft brush so that the retouching is blurred and not obvious (figure 6).

Dimensione: 128 px

Durezza: 6%

Fig 5 The texture of the same wood in fig 5 after the color calibration procedure and photo retouching to make it seamless. In the center, on the right and at the bottom, where the texture has been repeated, the discontinuities are no longer visible.

5. Conclusions

There is scientific research that has already dealt with the problem of material management in rendering software in the context of radiometry, with physically more correct solutions than the one presented in this essay. However, this basic research presents problems for application in the design practice. A first problem is that software tools that use radiometric calculation models have not yet been implemented by commercial Lighting CADs. Also, if a designer wanted to use very accurate software, such as Radiance® (Ward and Shakespeare, 2004) or Maxwell Render® (Next Limit, 2021), he would not have the radiometric information (BRDF) of the actual materials they want to use in their design. There are databases of the BRDF for some materials, but they have no connection with actual design (Dana *et al.*, 1999; Filip, Vávra and Mikeš, 2009). This is also the reason why commercial Lighting CADs use colorimetric information for material descriptions.

This paper proposes an application solution to the problem of color management of homogeneous and textured materials used in design practice with commercial Lighting CAD software tools, starting from real materials that designers may have in their hands during the project development. The proposed solution is based on a digital colorimetric approach, so it does not take into account the open issues in digital color reproduction introduced in the 2nd paragraph (Rizzi, 2021).

6. Conflict of interest declaration

The author declares that nothing has affected his objectivity or independence in the production of this work. There are no actual or potential conflicts of interest, including financial, personal or other relationships with other people or organizations.

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9. Short biography of the author

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