

AN APPLIED WORKFLOW TO ACHIEVE RELIABLE COLORS IN BIM SOFTWARE RENDERINGS

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Abstract

The BIM methodology offers the various professionals involved in the design phase a database of information relating to the project's various components. Among this information, colour can be reported in two ways: at the level of digital data to be inserted in the database and at the level of representation in the visualization design images, which are the renderings. Although having to follow standard and specific procedures depending on the device used, the correct acquisition of the colour to be used in the project and its insertion as data is an overall linear process. Instead, the discussion on maintaining the consistency of colour between reality and its representation in the renderings is more complicated and open. This article presents a general and as effective as possible study regarding resolving this problem, analyzing the various criticalities, and proposing possible solutions using the tools currently offered by BIM software with the help of external plug-ins.

Keywords

Color constancy, BIM, rendering, color profile, virtual camera calibration

1. Introduction

The BIM methodology offers to various professionals an accessible database of the project to be carried out and subsequently maintained. Among the various information available and to be foreseen in the design phase, the colour of the finishes to be used is of fundamental importance. In the BIM area, the designer can return colour in two ways. The first consists of attributing a particular colour to a particular architectural element. The second involves using renderings, predictive photorealistic synthesis images that communicate in a photometrically correct way the colour rendering of that architectural detail within the project environment.

In the first case, to maintain a consistency of the colour that the designer wants to use between a particular sample and its attribution to the element as information to be returned to those who consult the project database, presupposes the use of a series of standard rules and procedures to follow and respect carefully (Guarini & Rossi, 2019). In the second case, maintaining this colour consistency appears highly complex as the factors that influence the final image are numerous and sometimes complicated to reproduce precisely.

2. Premise

Colour management is necessarily influenced by the devices used, in the acquisition and in the display phases. A correct procedure has a necessary and not sufficient preliminary condition: the periodic calibration of all the instruments involved. In the acquisition phase via scanner, this calibration must be carried out using professional software and reference colour tables (see Figure 1) (Guarini, 2020). In this way, it will be possible to scan an image together with a corresponding ICC profile.

In the acquisition phase via camera, the shots of the material sample must be accompanied by shots in which there is a Color Checker colour table (see Figure 2) (Rodney, 2005) (Guarini & Rossi, 2021), in order to generate a colour profile associated with that particular device and those particular light conditions in which the shots were taken.

In both cases, the acquired images are converted to the sRGB colour space, the standard for CAD systems. Even the output devices, printers and monitors, must all be calibrated appropriately. Especially when working and viewing on the monitor, even the surrounding environmental conditions must follow specific rules so that the

colours returned comply with the sRGB standard (Stokes, Anderson, Chandrasekar, & Motta, n.d.).

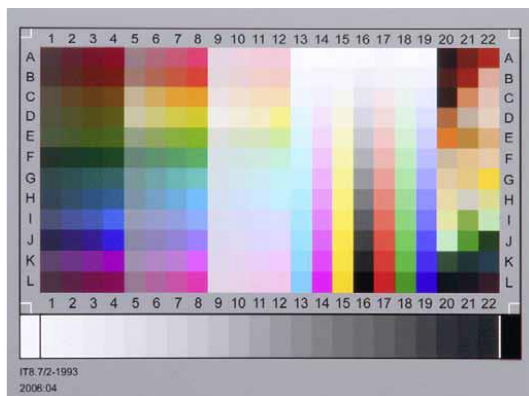


Fig. 1: Calibration of the Scanner using a reference colour table

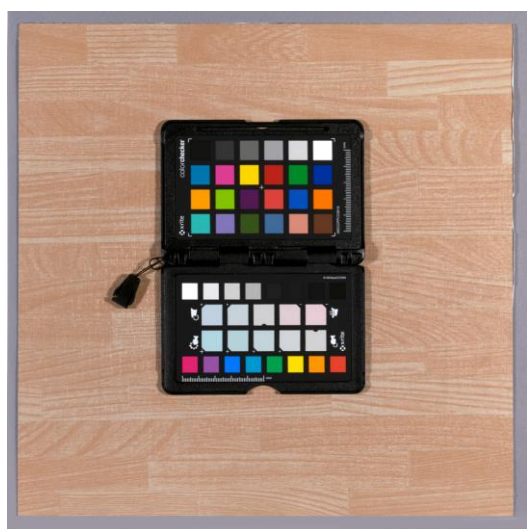


Fig. 2: Calibration of the Camera using a Color Checker colour table

3. Texture input

Most CAD systems are unable to manage colour spaces. When inserting a texture inside a slot of a particular property of a material, it is assumed that it complies with the sRGB standard (Nielsen & Stokes, 1998). On images downloaded from the internet, this may be as true as it may not be. A check should always be done through programs capable of managing colours. However, it is always preferable to enter textures whose origin is certain and obtained through professional and correctly calibrated devices. Before being imported, they should be converted into the sRGB colour space.

Even in the software used in the BIM methodology, among which we can mention Autodesk Revit ('Autodesk Revit', 2021), Colour Management is not provided, so when the application receives a raster image as data, it assumes that this is with an sRGB colour profile. The use of specific plugins for rendering, such as V-Ray for Revit ('V-Ray for Revit', 2021), allow some more options when attributing textures and choosing the sRGB space (see Figure 3).

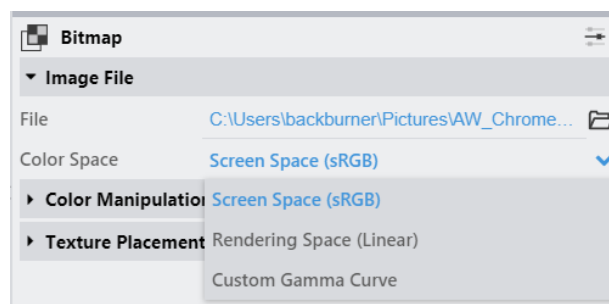


Fig. 3: Choice of the Colour Space when loading textures in V-Ray Materials

4. Materials

The choice of finish type also affects the color represented in the forecast rendered images. A material that reflects diffuse light will certainly look different than one that reflects specularly. It is therefore important to choose an appropriately set source material from the BIM library. It would be even better to start by building the material from scratch by setting the various properties as correctly as possible and respecting the law of conservation of energy, according to which a material cannot reflect or transmit more light than it receives.

Both the generic material supplied with Revit, and the native generic material of the V-Ray plugin, divide, albeit with different vocabularies, the light that interacts with the surface into: diffuse reflected light, specularly reflected light and refracted light. We focus here to avoid contradictory input in the generic V-Ray material. The user can individually set, using a slider or with the "Value" parameter of a chosen colour, the quantity of light reflected in a diffuse way (Diffuse) (Rossi, 2007b), the quantity of light reflected in Specular mode (Reflection) (Rossi, 2007a) and the amount of light transmitted (Refraction). To use a physically correct material, the sum of these

individual components, expressed as a measure from 0 to 1, must never be equal to or greater than 1 in total. For example, a white plaster wall has a very high percentage of diffuse reflection, about 85%, and a low percentage of specular reflection, maybe 1%, and a zero percentage of refraction. $0.85 + 0.1 + 0 = 0.95 < 1$.

Suppose the chosen finish is not of a homogeneous colour but has a texture such as the grain of wood or marble, a surface of a fabric, a series of bricks with the relative joints. In that case, it is necessary to use a texture image obtained through acquisition with calibrated tools and then to convert it to the standard sRGB colour space mentioned in the previous paragraph. In the case of the V-Ray plug-in, changing the value of the Diffuse parameter is irrelevant, as the quantity of light reflected in a diffused way is given by the Color Value, which varies from pixel to pixel as it is not homogeneous. Hence the importance of entering the texture with the correct colour space and compliant with the standard for CAD systems, namely sRGB. In the image (see Figure 4), it is possible to observe how, if a texture is used for the Diffuse property, the diffuse parameter itself is irrelevant since the amount of Diffused light changes according to the Value (Brightness) of the selected pixel that is sampled.

the type of lighting present. There are two possible scenarios: natural light (day or night) and artificial light.

5.1 Natural Light

Regarding the first, the Autodesk Revit software can simulate the light coming from the sun and the celestial vault in a few simple steps, allowing the user to set the geographical position of the project, the orientation of the North, the time and the date of the simulation. The use of the V-Ray plug-in, also assisted by the use of its proprietary materials, shortens the calculation times and presents more refined results. However, as regards the position, orientation, date and time, it still relies on the settings set in Revit.

5.2 Artificial Light

The second case that of artificial light, is instead more complex to manage. The reason is that each luminaire that the designer wanted to use in the project emits light in different ways, which are difficult to reproduce in the software except by relying on specific data that can only be retrieved from the supplier who made that luminaire (Goesele, Granier, Heidrich, & Seidel, 2003). Among the various photometric quantities

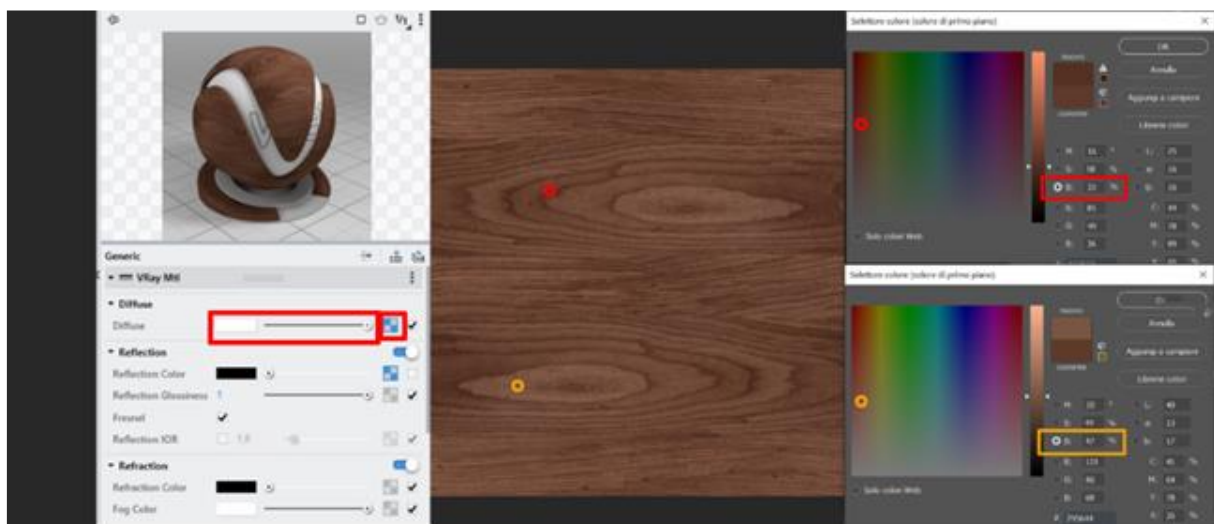


Fig. 4: Texture loaded into the Diffuse slot in the V-Ray Plugin Material

5. Illumination

The rendering of the colours chosen in the design phase can change radically depending on

characteristic of light, two are fundamental for the correct reproduction of how light propagates from a particular device: the colour temperature and the luminous intensity (Choudhury, 2014). The first can be easily inserted in the majority of three-dimensional modelling software and BIM

software. It is sufficient to read the value from the product data-sheet and report it in the corresponding field given by the software. On the other hand, the second cannot be entered by hand since it is a three-dimensional spatial distribution of a quantity that varies in direction and size. However, this distribution can be measured by special laboratory instruments. A "goniophotometer" can measure and replicate the diagram of light intensities in 3D. This diagram can be distributed to designers in the form of a text file that contains a three-dimensional coordinate table. This file has the *.IES extension and can be read and displayed in 3D by particular viewers (see Figure 5). It can also be inserted into modelling software as a property of artificial lights (Mangkuto & Soelami, 2017).

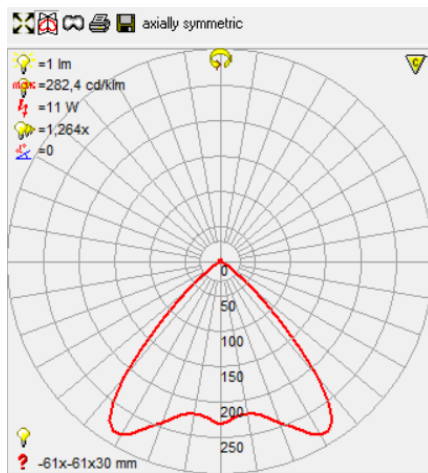


Fig. 5: Example of an *.IES file displayed by a freeware viewer

Therefore, it would seem simple, once the correct colour temperature value obtained from the technical data sheet has been entered and the *.IES file of the light intensity distribution has been obtained from the supplier, to replicate the light coming from a given luminaire correctly. However, there are several cases in which the interactions between the photometric measurements taken in the laboratory and the 3D geometry that simulates the device itself can significantly interfere with the correct simulation of the light distribution. The reason is that what is measured in the laboratory using the goniophotometer is the distribution of the light intensity coming out of the device, that is the set of physical geometries that make it up, including the lamp itself. The resulting distribution has a particular starting point, the so-called photometric ZERO. Suppose you want to associate

the photometric file with the 3D geometry that replicates the physical geometry of the lighting fixture. In that case, it may be necessary to position the photometric zero within the 3D geometry itself. The light intensity distribution could be hindered by the geometry, thus interfering with a correct photometric simulation (Siniscalco & Guarini, 2018) (see Figure 6).

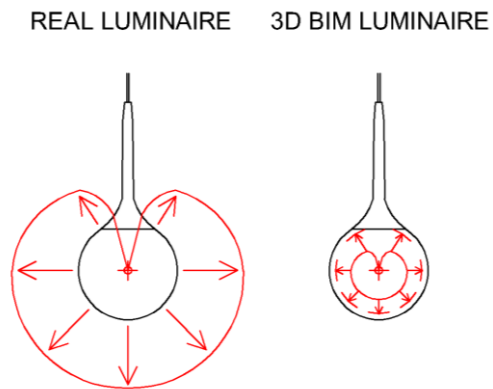


Fig. 6: Example of an *.IES file measured coming from outside the real geometry of the Luminaire and the same file inserted in the 3D geometry of a BIM model. Since in this type of Luminaire the photometric ZERO is inside the geometry, the light intensity distribution is hindered by the geometry itself

BIM software does not have tools to solve this problem, but the V-Ray for Revit plug-in offers as a solution an option that disables the casting of shadows from selected material. In this way, if a V-Ray material with this option disabled is associated with a particular 3D geometry, the geometry itself will not hinder the distribution of intensities given by the imported *.IES file, thus allowing the light to diffuse correctly in the scene (see Figure 7).

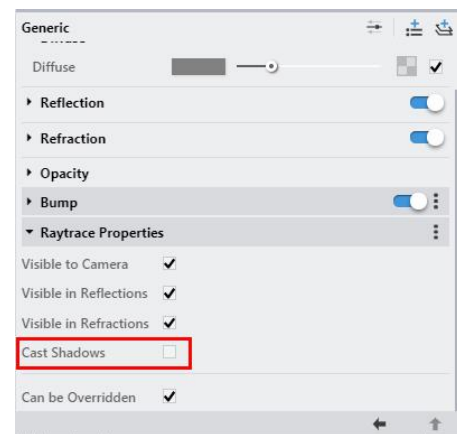


Fig. 7: Cast Shadows option of a V-Ray Material

6. White balance and exposure

The production of a photorealistic preview image is, in fact, comparable to a real photographic shot of an existing environment. Concepts typical of photography are therefore involved, such as white balance and the choice of the correct exposure to not chromatically distort the final result. It is, therefore, necessary to replicate in the software all the procedures that should be followed in a real shot.

6.1 White balance

Concerning white balance, BIM software allows you to set a colour temperature before making each rendering. To enter correct values, it is essential to know the colour temperature of the light sources involved (see Figure 8).



Fig. 8: Different appearance of an image depending on the Colour temperature of the light sources used

In the case of a simulation with natural light, it is necessary to know with which climatic conditions the designer wants to preview the project, whether with a wholly covered sky, with some clouds or clear. A good choice, in this case, is to use the settings given by the illuminant of the CIE D50, D55, D65 or D75 series, corresponding respectively to 5000K, 5500k, 6500K or 7500K ('CIE 51.2 — 1999, A Method for Assessing the Quality of Daylight Simulators for Colorimetry', 2001).

In the case of a scenario with artificial light, it is, instead, necessary to know the colour temperatures of the intended luminaires. If they all have the same colour temperature, enter that value in the software before rendering. If this were not the case, a weighted average of the various values involved should be used. This average would depend on multiple factors, including the number of sources present, their intensity, and

which sources are closest to the camera from which the rendering is to be calculated.

6.2 Exposure

The other important parameter to set for the correct colourimetric rendering of the simulation is the exposure (see Figure 9). The parameters of a real camera that affect the clarity of the image (film sensitivity, aperture, shutter speed) are not always referred to in the BIM software interfaces. Most of the time, a single dimensionless parameter is used, generally referred to by the term "Exposure", but that could also vary considerably the result depending on the software or even the plug-in used. The fact that the range of values that can be entered varies from software to software and from plug-in to plug-in contributes to increasing the inhomogeneity in the results obtained.

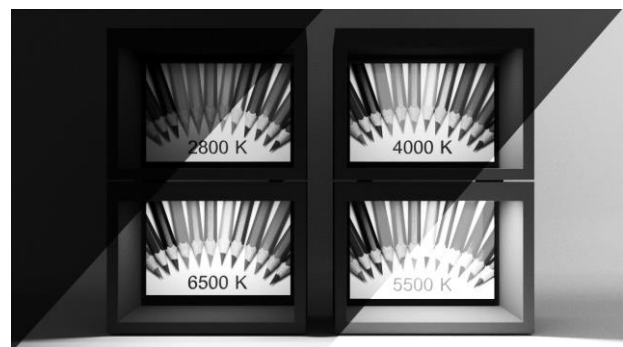


Fig. 9: Different appearance of an image depending on the Exposure setting of the simulation

7. A practical workflow

Given the large number of parameters involved, a good practice to obtain accurate colourimetrically corresponding images consists, as a first step, in trying to set all the parameters described above in the best possible way: the replication of the materials, the setting of the lighting and the exposure and white balance before processing the image. Then, a further refinement can be implemented in Postproduction, bearing in mind that some plug-ins, such as V-Ray for Revit, allow dynamic adjustments even before saving the final image. These adjustments are the same as those found in photo editing programs, including exposure and white balance, which can then be further refined with respect to the values set before the calculation. Furthermore, it is also possible to act

on the curves, on the tonal values, on the hue, the saturation, and the colours' balance (Sannino, 2019). Moreover, the V-Ray for Revit Framebuffer works by default in the sRGB space, but the plug-in also allows importing a specific ICC colour profile. However, having set the entire process chain so that the sRGB standard is respected, it would be counterproductive to adopt a different profile in the final step.

A possible aid in the final adjustment of the exposure and white balance levels could consist in positioning a fictitious object that represents a Macbet Colorchecker sRGB (see Figure 10) within the scene to be rendered. At that point, one could operate like in postproduction on a photograph of a real scene with a real Color Checker table inside it, using the notches of the gray scale as a reference. By keeping these last adjustments in the Frame buffer's memory, it is possible to exclude the dummy ColorChecker from the scene and proceed to final processing of the image, which will finally be saved.

An alternative to this last step carried out directly in the plug-in is to export the rendered image in a high dynamic format and then import it into a photo editing software, where it will also be possible to work in postproduction on the white balance and exposure levels.

8. Limits

There is a third characteristic of a light source that can influence how a colour is perceived by the observer: the Spectral Distribution. It can be measured, but nowadays, commercial CAD and BIM software can't be inserted in the property of a virtual light source (Chern & Wang, 2005). Suppose two different colours are intended to be illuminated by a luminaire with an incomplete or non-uniform spectral distribution. In that case, they could be perceived by the observer as the same identical colour. The designer cannot use BIM software to foresee this issue.

Another problem is because also the materials have their Spectral Radiance. So if a wall is painted with a very high saturated tint, the colour of the nearby object can result strongly influenced by this tint. This phenomenon is called "Colour Bleeding" (see Figure 11).

The Human Visual system can automatically correct this alteration. The ability to correctly perceive an object colour even if enlightened by a fragmented Light

Spectrum or influenced by nearby objects colour bleeding is called "Colour Constancy". Unfortunately, images produced by BIM software, especially when in the presence of different CCT light sources, cannot reproduce this automatic correction.

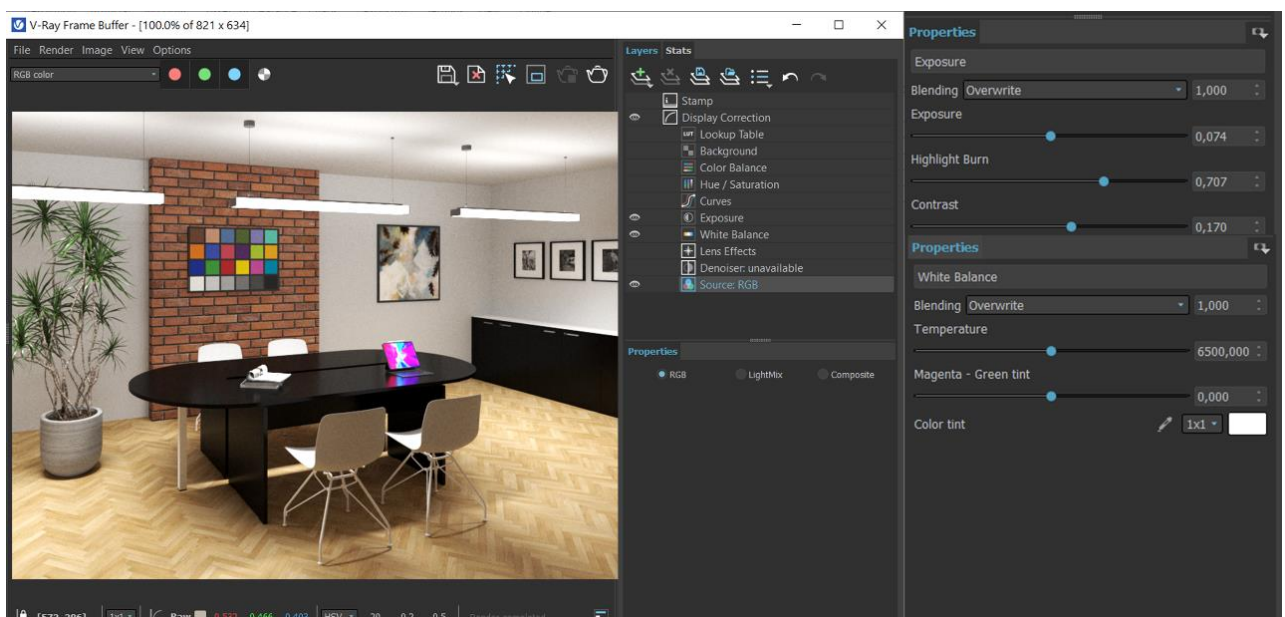


Fig. 10: Postproduction changes to exposure and white balance with the aid of a dummy ColorChecker directly within the V-Ray for Revit Plug-in

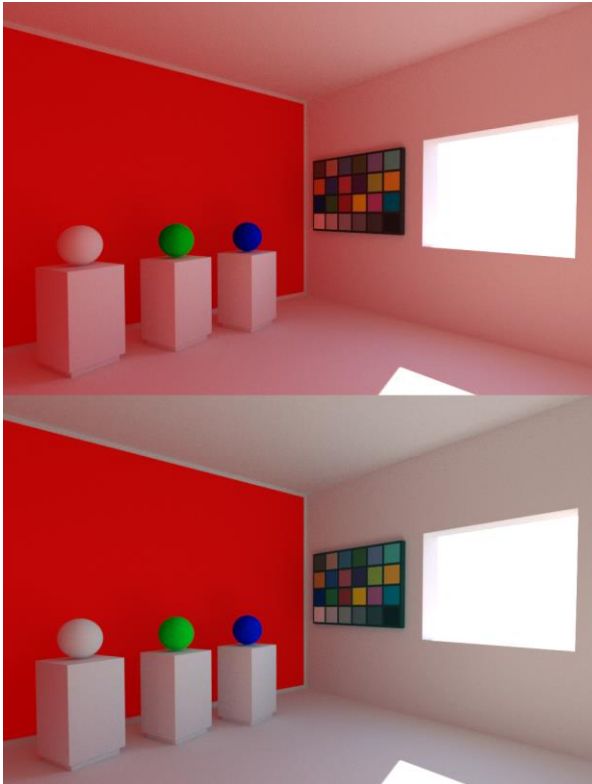


Fig. 11: In the Upper image, because of the “Colour Bleeding” the nearby objects colours are influenced by the highly saturated red tint on the wall. In the Lower image, how the Human Visual System should automatically correct this effect with “Colour Constancy”

9. Conclusions

In this article, we illustrated that, within BIM software, maintaining consistency of colour between the choice of an actual finish and its representation in the design visualization images is possible. Still, the topic involves numerous and complex aspects. The acquisition of the materials must be standardized, and their replication must comply with the law of energy conservation for a correct simulation of the interaction with light. The natural light and the artificial lights must be replicated correctly. About the artificial lights, the use of data provided by the manufacturers of the devices is an essential condition for a correct calculation. Finally, a proper exposure setting and white balance are indispensable conditions for a faithful representation of the colours perceived by the observer. These last two operations are recommended both before processing the rendering and subsequently in postproduction. Furthermore, at present, BIM software must also be supported by specific plug-in rendering engines

to solve problems of interaction between light and matter and assist in the postproduction process.

It must also be noticed that the actual spectral distribution of the light sources cannot be replicated in commercial software, which cannot autocorrect the colour bleeding effect. It could be a great help for the designer if, in future, BIM software will evolve to fill this lack between the digital visualization of the project and what should be actually perceived by the human visual system.

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