

A review on the open issue of color consistency in software for building information modeling systems and real-time visualization

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ABSTRACT

This text discusses the issue of color consistency in BIM and Virtual Reality. In recent years, due to an increasingly stringent regulatory imposition in public procurement, especially concerning the estimated workloads, the BIM methodology has become increasingly popular among professionals in the architectural design field. In the 2000s, the visualization of projects was mainly done through photorealistic static renderings or animations obtained from sequences of static images. However, with the evolution of Raytrace Rendering engines and the escalating computing power of available hardware, Virtual Reality and augmented reality have gained significant popularity among designers for visualizing and facilitating project comprehension among clients and other professionals involved. Once the color of a finish has been acquired through correctly calibrated devices and standard procedures, the problem of its correct representation arises. The Methods section of this paper describes the preliminary procedures used to obtain a trustful Design Visualization, in the Result section we list some currently available solutions and their characteristics, thus analyzing how the applications address the issue nowadays, providing tools that allow designers to optimize color consistency between the real world and different visualizations and guarantee imaging correctness and quality. In conclusion, we summarise the different approaches to give an overall view of the tools available for the Designers.

KEYWORDS color management, virtual reality, color consistency, BIM, real-time

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1. Introduction

Designers In the Construction field are increasingly adopting BIM methodology to create a virtual prototype of the building to be designed. This digital twin must be accompanied by detailed information on all the construction elements. At the same time, since the BIM methodology does not require great graphic detail, it can provide a low level of detail in terms of geometry, avoiding a negative impact on the weight of the file. Nevertheless, all BIM software have basic, non-highly professional Visualizing and Rendering features, and the graphic detail of the images produced as a result can't be satisfactory, especially on the furnishing elements. The BIM model's detail level is only appropriate for general external architectural visualization. In recent times, Virtual Reality and Augmented Reality applications are playing a significant role in indoor architectural visualization, surpassing the usual static renders. This is due to the evolution of real-time algorithms and rendering engines (Möller, Haines and Hoffman, 2018), AR / MR techniques (Alhakamy and Tuceryan, 2020), and the hardware capacity of modern video cards (Thoman *et al.*, 2022). Furthermore, some studies have shown that, especially in daylight simulations, the perception of space by the end-user was remarkably accurate (Chamilothori, Wienold and Andersen, 2019). Thus, integrating the BIM outcome with a VR visualization tool represents a practical solution to project presentation. This theme has been studied and good results have been obtained, especially in artificial light scenarios (Natephra *et al.*, 2017). This paper aims to find a way to represent the BIM model through new interactive techniques, improving the quality of the model without affecting the weight in bytes of the native file and respecting color fidelity between the real world and the digital visualization. The proposed solutions are numerous and various. Previous studies presented workflows with multi-software applications (Wong *et al.*, 2019).

The paper plans out as follows. In Section 2, we describe the preliminary procedures to obtain a trustful Design Visualization, specifically: a correct acquisition of a Material Color (Section 2.1), the use of a specific digital material to better reproduce the interaction of the material with light (Section 2.2), and the procedure used to have a digital replica of the light setup (Section 2.3). In Section 3, we present the different solutions available today on the market. "Revit V-Ray and Chaos Vantage" in Section 3.1, "Revit and Enscape" in Section 3.2, "Revit and exporting in dedicated Real-Time Visualization Software" in Section 3.3, and "Revit and Unity Reflect" in Section 3.4. In Section 4, we briefly recap the results and present advantages and drawbacks of each provided procedure.

2. Methods

The designer must consider three essential aspects to ensure color consistency in the new interactive visualization. An accurate acquisition of the material Color. A correct replica of the interaction between the light and the material. A trustful reproduction of the lighting scenario. In the following, we describe in detail each one of these aspects.

2.1. Acquisition of the Material Color

CAD systems usually accept textures by default in the sRGB colorspace profile. To correctly represent a material's color, users should avoid using textures downloaded from the internet, as there's no way of knowing how and if they were acquired with a standard and verified procedure. It is also uncertain whether the conversion of the relative color profile of the device to the absolute sRGB has been completed accurately. The designer should therefore opt for a live acquisition.

There are two possible procedures, one photographic and one via scanner. In either scenario, the devices must be calibrated and have a relative color profile, periodically updated in the case of the scanner (Guarini, 2020) and obtained at the time of the shooting in the case of the camera (Guarini and Rossi, 2021). The whole procedure, as well as the environmental conditions, must be standard and reproducible. Scanner acquisition is a preferable choice, especially in the case of samples with a narrow section. The acquired texture must then be converted, using dedicated software equipped with a CSM Manager, into the absolute sRGB color space. If the texture has to be repeated several times on a surface, it will then be further refined in a photo editing program to be used seamlessly.

2.2. Interaction between Light and Material

A correct replica of the interaction between the light and the material is crucial for a reliable Real-Time visualization of the Project. PBR materials (McDermott, 2018) are shaders, introduced in recent times, that replicate this type of interaction quickly and effectively. Revit has recently introduced this type of material, however, they are still hidden and not easily accessible by the user (Fig. 1). When assigning materials in Revit, it is preferable to use these directly to facilitate compatibility and reduce work in Real-time Rendering applications. If the sample present in the library shows an exclamation point on a yellow triangle, the Revit material is not a PBR material.

PBR materials (Pharr, Jakob and Humphreys, 2023) are based on physical parameters that can be set through values or through specific texture images. The parameters

in which to insert the texture maps are always the same, regardless of the software used. Once the designer has obtained the maps in question, he must connect them to the respective map channels of the application he wants to use. Among the most important, we mention “Albedo,” relating to diffuse reflection of light, “Roughness” relating to surface imperfections of the surface, and “Height Map”.

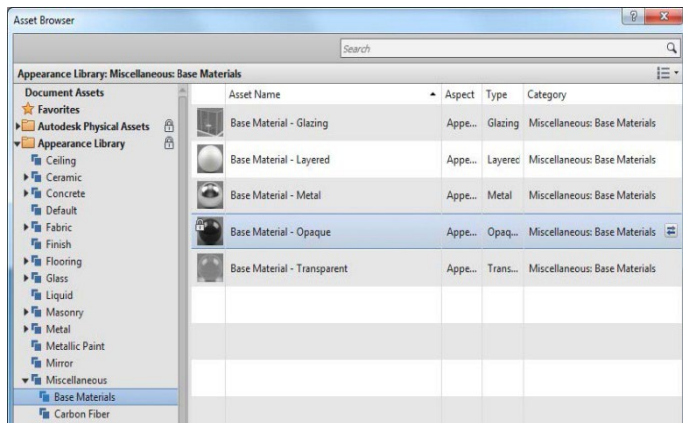


Fig. 1. Base PBR Materials in Revit

The Designer could find the textures on-line, as several sites offer pre-prepared textures for various channels. However, this workflow should be avoided due to a range of problems regarding acquisition's fidelity of the base color. Using a texture acquired with known and standard procedures would be advisable. Obtained this, free software allows producing all other textures from the first image. An example is Materialize (*Bounding Box Software - Materialize*, 2023). We outline that procedures for obtaining images with sRGB profile to be used in Albedo property tries to return color as faithfully as possible. Materialize is a free software that renders the maps of the other material parameters and produces a more realistic appearance to the final finish by acting on the glossiness of the material and its roughness. Unfortunately, they empirically reproduce the type of finish, and the result is often left to the designer's ability.

2.3. Lighting

There are two lighting conditions for carrying out design simulations where it is possible to evaluate the color rendering of materials: natural light and artificial light. The first is easier to manage since each real-time simulation software has simplified commands that reproduce daytime or nighttime lighting. The parameters to set up are not numerous and essentially concern the simulation's date and time, the project's position and orientation, and the atmospheric conditions of the simulation. The designer must always be careful not to modify the preset physical parameters, such as the sun's intensity and the solar disk's size, to avoid incorrect simulations regarding the quantity of light and the visualization of shadows. The artificial light

condition requires more attention since the designer should use the accurate photometric data of the lighting fixture that they want to use in the environment. This can be supplied by the appliances manufacturers. The most widespread methodology consists in entering the data relating to the light intensity through photometric files downloaded from the manufacturers' websites and the data relating to the color temperature of the sources by entering them manually from the technical data sheets of the device. Almost all real-time viewing software supports the insertion and utilization of such files and color temperatures. It is also necessary to verify that the software has available options or tools that allow using the actual intensity distribution given by the file without this being occluded or modified by the 3D geometry of the device itself.

3. Results

After an accurate acquisition of the material Color, the utilization of the PBR shader, and a trustful reproduction of the lighting scenario, a dedicated application or plugin is still required to easily view the project in real-time.

The BIM software has a module for viewing the rendering of the project. However, it has a limited set of tools and needs to solve the problems related to the interaction of the photometric solid within the lighting fixture. Additionally, there is no module for real-time viewing. Some integrated and cloud-based solutions, such as "Revit Live" (Revit Live | Autodesk, 2020), were implemented but were subsequently discontinued.

Several alternative solutions are currently available to address this deficiency, given the ever-increasing diffusion of Realtime Visualization and Augmented Reality. Some professional rendering engines developed by companies with years of experience in visualization have developed additional real-time applications to import the scenes rendered through their plugin. We can mention V-Ray for Revit (*V-Ray for Revit*, 2021) and Chaos Vantage (*Chaos Vantage – Pure ray tracing in real-time* | Chaos, 2022).

Some Architectural Plugin solutions allow viewing the model easily through the live synch feature. Examples are Enscape and Lumion (*Lumion 3D Rendering Software | Architectural Visualization*, 2022).

Another alternative is to import the BIM model using a standard file format into leading software in the sector, such as Unity (Unity, 2022a) and Unreal (*Unreal Engine 5*, 2004). Software companies are increasingly developing plugins to allow BIM users to take advantage of Real-Time raytraced project visualization. These plugins are simplified versions of their corresponding vertical software

of the sector. In this way, the work of the designer can be simplified. Unity Reflect (Unity, 2022b) is an example of this approach.

3.1. Revit VRay and Chaos Vantage

VRay for Revit is a plugin that expands the possibilities of Revit in terms of project visualization. It solves the interaction problems of the photometric solid within the luminaire and can perform lighting analysis on photometric quantities. It has photometrically correct materials, the VRay Materials, which allow importing textures acquired specifically with sRGB profile, thus guaranteeing color consistency in the representations. The software company that developed it has also implemented an application dedicated to real-time visualization, Chaos Vantage. It is possible to export the entire model from VRay for Revit in a file *.VRayscene, which can then be imported into Chaos Vantage.

In this case, the materials and natural light are managed entirely within VRay for Revit, while the lighting fixtures and photometric files are set up in Revit. Once the file has been imported into Vantage, it is possible to explore the model in Realtime and with the same rendering quality as VRay. It is also possible to apply other materials to the scene, including those previously created and assigned within VRay for Revit. The lighting fixtures can also be switched off and dimmed.

3.2. Revit and Enscape

Enscape (*Enscape™*, 2022) is a Real-time Rendering Plugin that can be used in various software, including BIM software and Revit. Once the plugin is installed, the user can transport the BIM model to an Enscape instance, establishing a dynamic link between the model and its visualization. In this case, the Enscape window acts as a Real-Time viewer of everything modified in Revit (Fig. 2).

The materials and the lights are then set directly in the BIM software. For this reason, to obtain consistency between the purchased color and the one represented, the procedure and the precautions to follow are the same in order to import a color and a texture into the native materials of Revit (Guarini and Rossi, 2019). PBR materials should be used as much as possible. Additionally, regarding the influence of the correct simulation of artificial light on color, following the recommendations indicated in the Methods section of the text is strongly recommended. This is generally a valid prerequisite for a solid insertion of lights into the BIM software. Regarding the simulation of natural lighting, the corresponding parameters are set directly by the user and dynamically in Enscape. To efficiently represent the project, the models should be in high detail, with a plentiful number of polygons to better represent curved surfaces

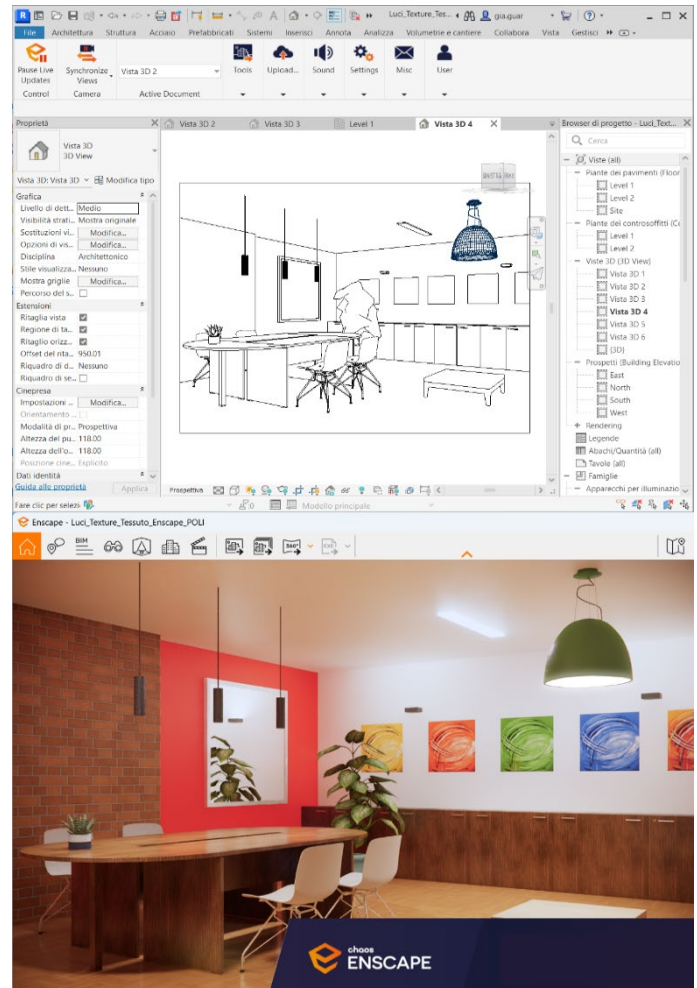


Fig. 2 – Revit model Visualized in Real-time in Enscape

and the shades of color on the various finishes. This would weigh up the BIM file. The Plugin solves this problem. The low-detailed Revit families are replaced in the rendering phase with 3D models developed within an Enscape proprietary Editor. With this expedient, the BIM file is light in Bytes, while the Real-Time representation is in high quality.

The Plugin has a custom library containing ready-to-insert templates. If the designer wants to insert models unavailable in the library, using the Enscape Editor to import different 3D file formats is possible. This solution enables overcoming the Revit mapping coordinate missing features. The BIM software has a limited set of tools for these purposes. Importing a 3D model into the Enscape Editor also imports the mesh mapping coordinates of the imported surfaces.

Regarding the color rendering in Enscape, the Plugin can use Revit materials. However, it also has tools to create dedicated materials, which replace the native materials in the Real-Time window or even directly in Revit if the designer decides to apply them permanently. These materials are configurable within the project and in the Enscape Editor for importing into objects. Materials that can be created in Enscape are PBR based. For a correct

color rendering, the texture with the sRGB color profile to be used is the one that must be inserted in the "Albedo" slot, which refers to the light reflected in a diffused way. In addition, if the designer opts to use Revit materials to view the project with Enscape without making any replacements, it is advisable to use the PBR materials directly, which have already been available in Revit since 2019.

3.3. Revit and export in dedicated Real-Time Visualization Software

Using vertical applications for Real-Time visualization, among which we can mention the best-known "Unity" and "Unreal," is another possible way to view the BIM model in interactive mode. Both use PBR materials, which are, in fact, the standard for a physically correct representation of materials and their finishes. Taking up and completing what is described in the Method section, the parameters present in this type of material are several, but among the leading properties, we can mention: color (or Albedo), roughness and metalness, that is, if the material is a dielectric or metal. These three properties are present in every solution we are describing here. Each of these affects the final color perceived by the observer. Still, the one that most affects the user is the first: Albedo. If assigned as a texture, this should always be entered with the sRGB color space.

Each software may present these parameters differently. For example, the Albedo is named "Basic Color" in Unreal. The interface of the Unreal Material Editor shows an Editor of nodes connected within a tree structure. The various parameters are the nodes connected to the primary node representing the material on which the designer works. In the node relating to the texture to insert "Texture Sample" and connect to the "Basic color," it is possible to choose the texture to use. In the texture properties, it is possible to specify whether the inserted texture should be in the

sRGB color space (Fig. 3). As previously explained, this option must always be activated.

Procedures for importing the BIM model into Unreal are available in several ways. The most straightforward and immediate is using the *.fbx format (Joy, R. and Raja, 2022). However, this is a geometric format, and its use can lead to the loss of information of the project's BIM database. This problem can be solved using a third-party plugin, such as "Datamisth" (*Datasmith Exporter Plugins*, 2004), which allows associating information not present after exporting the *.fbx file. Using this Plugin, that should be installed on Revit and enabled on Unreal, it is possible to keep track of the material replacements made during the import of the *.fbx file, and re-apply them automatically if needed to re-import the model following some modification or variant of the project. This procedure is longer and more complex than the Enscape Plugin alone, as it requires several steps and attention from the designer.

The visual render and Level of Detail of the BIM model exported should be more sophisticated than the native Revit model, where the furniture's level of detail and development cannot have surface models composed of excessive polygons. So even in Unreal, as with Enscape, replacing the Revit families with more complex geometries can enhance the visual result.

Like Unreal, Unity is another Vertical program dedicated to Real-Time Rendering. Also in this application the materials used are PBR and there is the possibility to specify whether the texture should be used with the sRGB color profile (Fig. 3). If the texture is assigned to the Albedo color, the sRGB profile must always be specified. A study (Wong *et al.*, 2019) has shown that in this case, a feasible calculation method of lighting illumination in Unity is lacking, since both the unit of light intensity in Unity and its

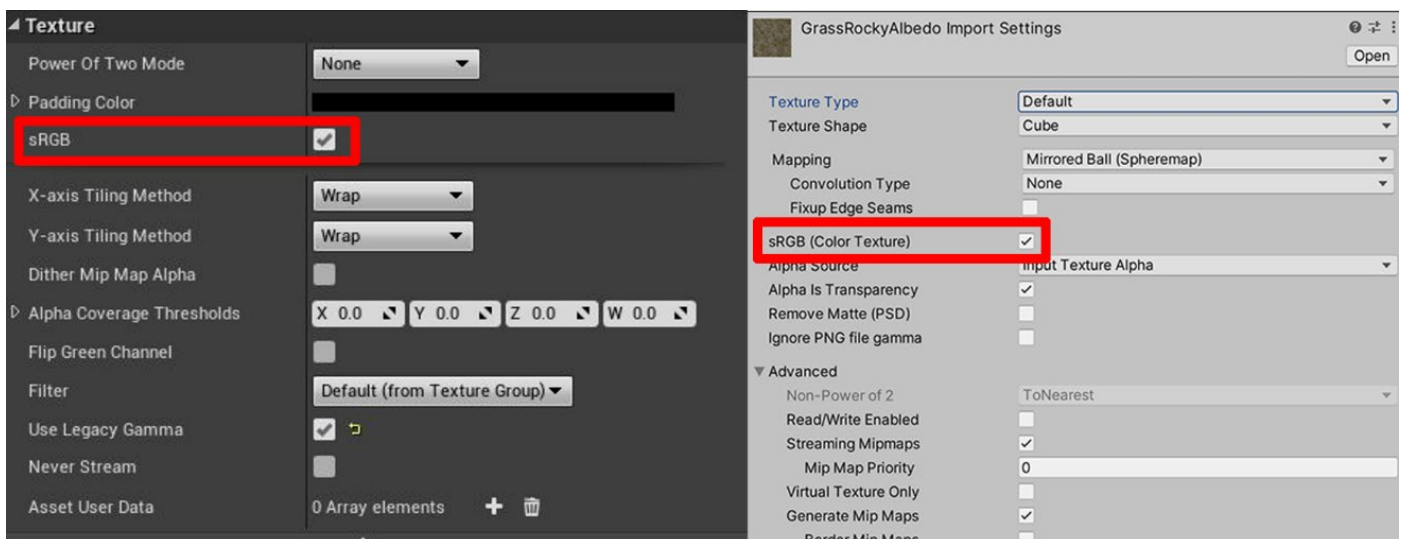


Fig. 3 – sRGB Option in the Texture Properties of Unreal Engine and of Unity

conversion relation with the real-world unit of luminous flux are not available in the official documentation. So, in this last approach the real lighting effect can't be reproduced.

3.4. Revit and Unity Reflect

The use of vertical software in Real-Time representation guarantees, on the one hand, high-level performance and a great variety of tools for the designer. As a downside, the export process can be counterintuitive and increase the number of skills the designer must acquire to obtain the desired result, discouraging this approach. Because of that, some Real-time software houses have decided to develop specific versions of their applications dedicated to the BIM world that interface directly with Revit and facilitate the utilization by BIM specialists. An example of dedicated application is "Unity Reflect," which is derived from the Unity application. The application installs a new tab in the Revit ribbon, from which the designer can easily export the BIM model to the Unity Reflect viewer. Any changes made in the Revit model, both in the geometry and the material, are automatically updated in the Unity Reflect model. The model imported into the viewer is completed with all BIM data without the need for third-party export programs. To be consistent, the materials' color properties must be correctly set in Revit. Also, in this case, it should be preferable to use PBR material in Revit since Unity Reflect does not have the tools of the central Unity program; it is simply a 3D viewer of the BIM model.

4. Conclusions

This Study describes some available solutions to visualize a BIM model through Real-Time rendering, trying to maintain consistency between the actual colors chosen for the finishes and those represented in the design visualization. It has been shown that to achieve this result, the methods used are: a) acquire the textures of the materials with standard procedures and periodically calibrated tools, having care to convert the relative color profile of the devices into the absolute sRGB color space; b) use the PBR materials, if possible, within the BIM software, to correctly simulate the light-material interaction; c) correctly simulate the possible lighting conditions.

The study results show alternative solutions, which can compensate for the lack a module dedicated to Real-Time in the BIM software. One solution is to use the "VRay for Revit" plugin, which in addition to creating traditional professional renderings, can export the scene to the "Chaos Vantage" Real-Time application of the same software house. Another solution is using rendering engines such as "Enscape" or "Lumion", which allow a live connection with the BIM software through a special plugin

for Revit. It is also possible to export the BIM model to programs specifically dedicated to the Game Engine and Real-Time Visualization, such as "Unreal" and "Unity". Finally, we can mention the possibility of using specific BIM versions of previously listed vertical Real-Time software, such as "Unity Reflect".

These are just some of the possible solutions in the designer's toolset, which can vary in terms of typology and applications available. Indeed, with the evolution of current technologies in a dynamic and rapidly expanding field, we hope there will be a convergence towards a reduced number of solutions for professionals.

5. Conflict of interest declaration

The author declares that nothing has affected his objectivity or independence in producing this work. Neither the author nor his immediate family member has any financial interest in the people, topics, or companies involved in this article. Neither the author nor his immediate family member had a professional relationship with the people and companies cited in this article. Neither the author nor his immediate family member are involved in a legal dispute with the people and the companies mentioned in this article. No conflict of interest, including financial, personal or other relationship with other people and organizations within three years of beginning the submitted work that could inappropriately influence, or be perceived to influence, this work.

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