# Photopia Simulation Accuracy Considerations

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## Abstract:

Photopia can produce accurate optical simulations, but the accuracy is a function of many factors. Some of these are listed below, including factors that affect the accuracy of measurements to which the simulation results are compared. Obtaining accurate simulations and measurements both take great care, so attention to these details needs to be respected.

## Accuracy metrics:

- Optical efficiency
- Intensity distribution
- Irradiance/illuminance distribution
- Spectral/colorimetric values

## Factors affecting simulation accuracy:

- Optical component geometric tolerances
- Optical assembly tolerances
- Light source modeling
    - Geometry
    - Material properties
    - Luminous properties
    - Spectral properties
- Material modeling
    - Total integrated reflectance and transmittance
    - Reflected and transmitted scattering properties

## Factors affecting measurement accuracy of the device under test (DUT):

- DUT mounting location and orientation
- DUT output stability
- Temperature effects on absolute light source output
- Calibration of radiometer, illuminance meter or spectrometer
- Cosine correction of irradiance/illuminance sensor
- Angular accuracy of goniometric device
- Positional accuracy of irradiance mapping device
- Stray light management & adjustments for lab measurements

## Design sensitivity:

Not all optical systems share the same level of sensitivity to the system geometry, but they all have some dependence on the system variables. Designs that include highly polished optical component surfaces & small light sources are generally those most sensitive to the system geometry. However, these types of systems also generally have materials that are more straight forward to characterize. Optical systems that include parts with more light scattering/diffusing properties are generally less sensitive to their exact geometry configuration, but the intensity distribution, luminous appearance and total optical efficiency are a strong function of the specific light scattering properties of each of the components. Characterizing the detailed light scattering properties of materials is much more challenging.

## How does Photopia help to produce more accurate results?

While certain aspects such as part and assembly tolerances, measurement system accuracy & light source output during testing are beyond Photopia's control, Photopia does help with aspects it can control. Two significant factors affecting simulation accuracy are lamp and material modeling properties.

To ensure accurate ray (photon path) emission, Photopia source models include the 3D geometry of all emission surfaces including plasmas, variable radiance across the emission surfaces, material properties for all optical parts of the source, spectral details including how they vary across the emission surfaces and over the emission angles and total radiant output power. All these properties are defined from physical light source measurements whenever possible for models included in Photopia's library. The LTI Optics lab includes the ability to measure light source intensity distributions, spectrum over emission angle, spectrum over emission area and light source geometry.

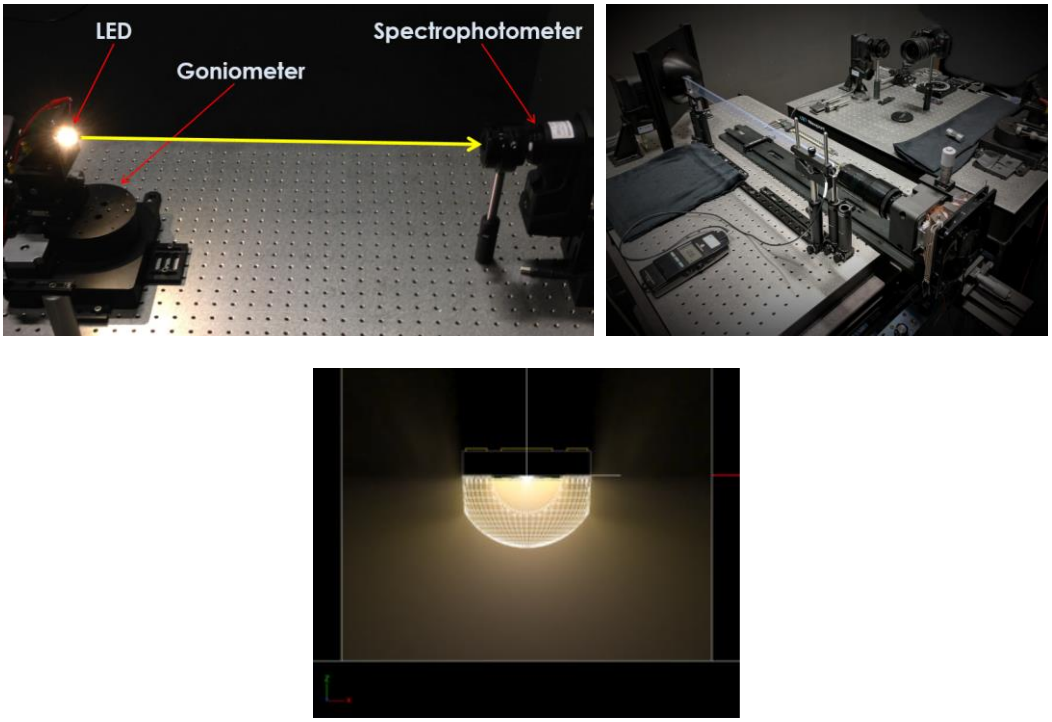

**Figure 1: The top images show some of the optics lab components at LTI Optics. The bottom image shows a Photopia LED source model for the Cree XP-L 3000K LED. The model includes the LED geometry, lens and base material properties, and the variable LED chip spectral properties that change from bluer in the beam center to more yellow at the wider emission angles.**

To ensure accurate ray interactions with optical components, material properties include total integrated reflectance & transmittance as a function of the light incidence angle and wavelength, light scattering properties upon reflection & transmission as a function incidence angle, index of refraction and extinction coefficient as a function of wavelength and particle scattering properties within refractive materials, including wavelength conversions for phosphors and fluorescing particles. All these properties are defined from physical measurements whenever possible for materials included in Photopia's library. LTI Optics has a custom built HDR imaging based BSDF measurement device and several integrating spheres configured for directional reflectance and transmittance measurements.

**Figure 2: These images show the camera & screen in our HDR imaging based BSDF measurement device, a laser directed through an anisotropic linear diffuser from Bright View Technologies from about 30° off-axis from the micro-prismatic features, and the simulated light scattering properties from 4 different material orientations with respect to the incoming light direction. The image showing the green laser directed through the material has a similar material orientation as the 2nd simulated orientation in the image on the right.**

# Examples of parameters affecting simulation accuracy:

## Wide beam LED optic

The first example optical design is a wide beam, IES Type V square distribution LED lens optic. The general optic style is shown in figure 3. The plots shown in figure 4 show the measured and simulated intensity distributions in 2 planes. The first plot shows the distribution along the 45° plane while the second plot shows the distribution along the 0° & 90° planes. The simulation was done with lens geometry obtained from a physical scan of the molded lens part. This ensured the simulation geometry matched the physical geometry as best as possible. The simulation results are a strong function of the lamp model properties, as this study was originally pursued to compare how a Photopia source model based on the actual LED geometry compared to a source model based on a "ray set" produced from luminous images of the LED. As a reference, figure 5 shows the results from the ray set simulations, which generally had much less accurate ray emission point locations. That is a critical factor when the optical part is so close to the light source. This comparison was done in collaboration with Ruud Lighting, later acquired by Cree Lighting.

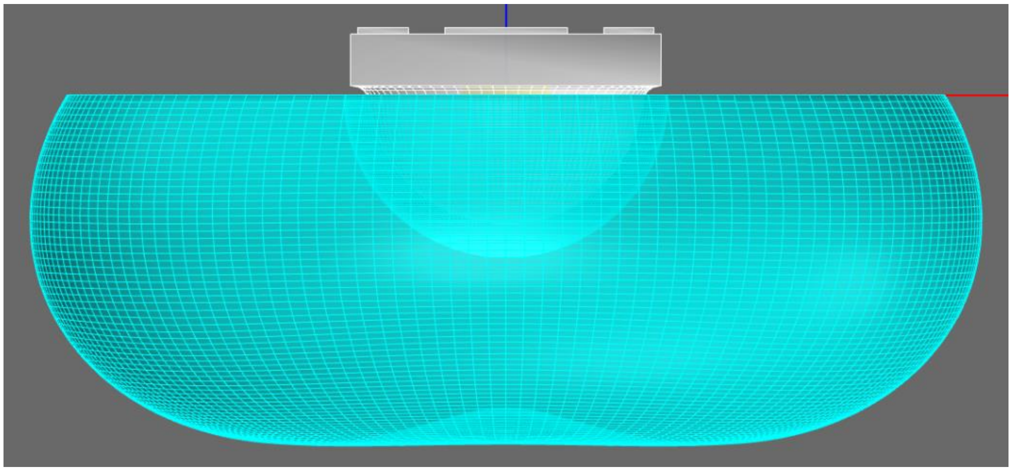

Figure 3: LED optic style for wide beam, IES Type V square distribution.

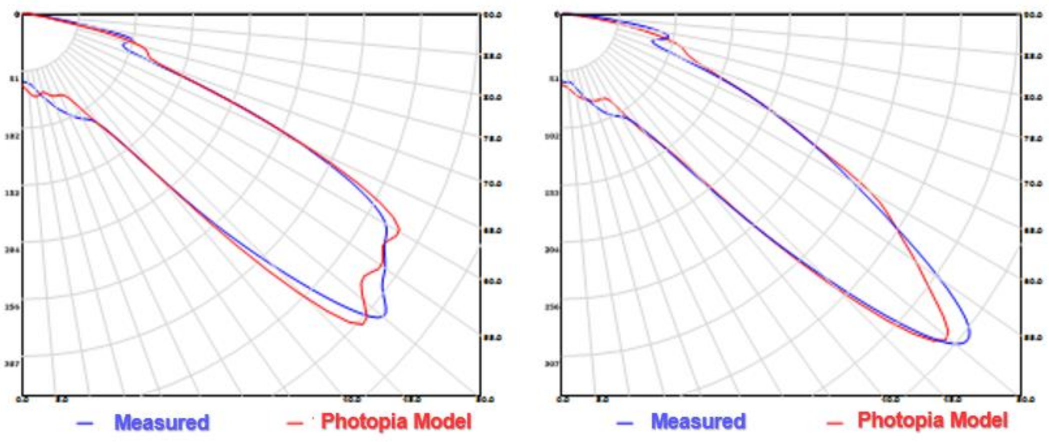

Figure 4: Comparison between the measured and simulated intensity distributions in the 45° plane (left) and 0°/90° planes (right) using the native Photopia lamp model based on the actual LED geometry.

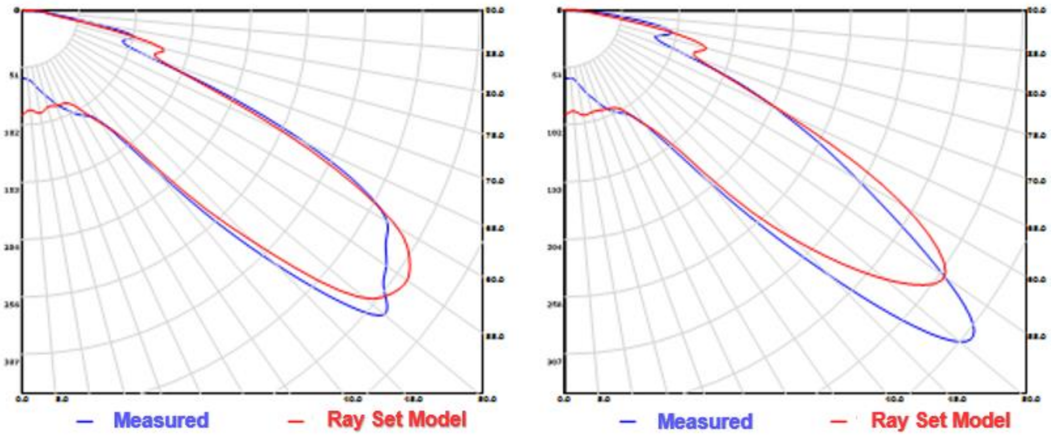

Figure 5: Comparison between the measured and simulated intensity distributions in the 45° plane (left) and 0°/90° planes (right) using a "ray set" representation of the LED, which had less accurate ray emission point locations.

## TIR Collimator lens optic for a dental light head

The second example illustrates the sensitivity of optical geometry tolerances in a highly polished, narrow beam TIR (total internal reflection) collimator style LED optic as shown in figure 6. The measured profile for the outer TIR surface was measured to be +/- 0.1mm from the design profile. Although this lineal offset would seem to be quite accurate, the important geometric factor is the surface normal across all points of the optical surfaces. Because the lineal offset was both to the inside and outside of the designed lens profile, the surface was wavy compared to the design profile as shown in figure 7 and the surface normal therefore varied by more than was acceptable. The consequence of this small tolerance variation was that the beam produced by the TIR surface spread light beyond the desired target region, as shown in the middle image of figure 8. This was not acceptable for this type of lens, as the extra beam spread causes glare into the patient's eyes. The bottom image of figure 8 illustrates how Photopia predicts the beam spread beyond the target image and matches the measured beam performance when the simulation uses the same geometry as the physical lens part.

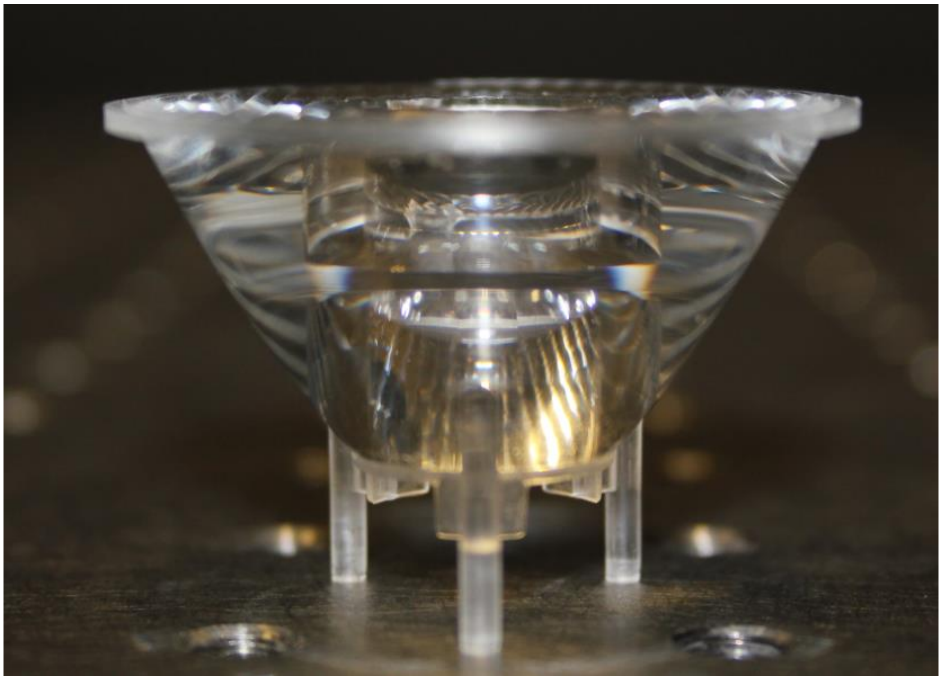

**Figure 6: Image of the physical optical part for the TIR collimator lens. The lens included linear ribs across the central convex lens and flat outer surface to add horizontal spread to the beam pattern.**

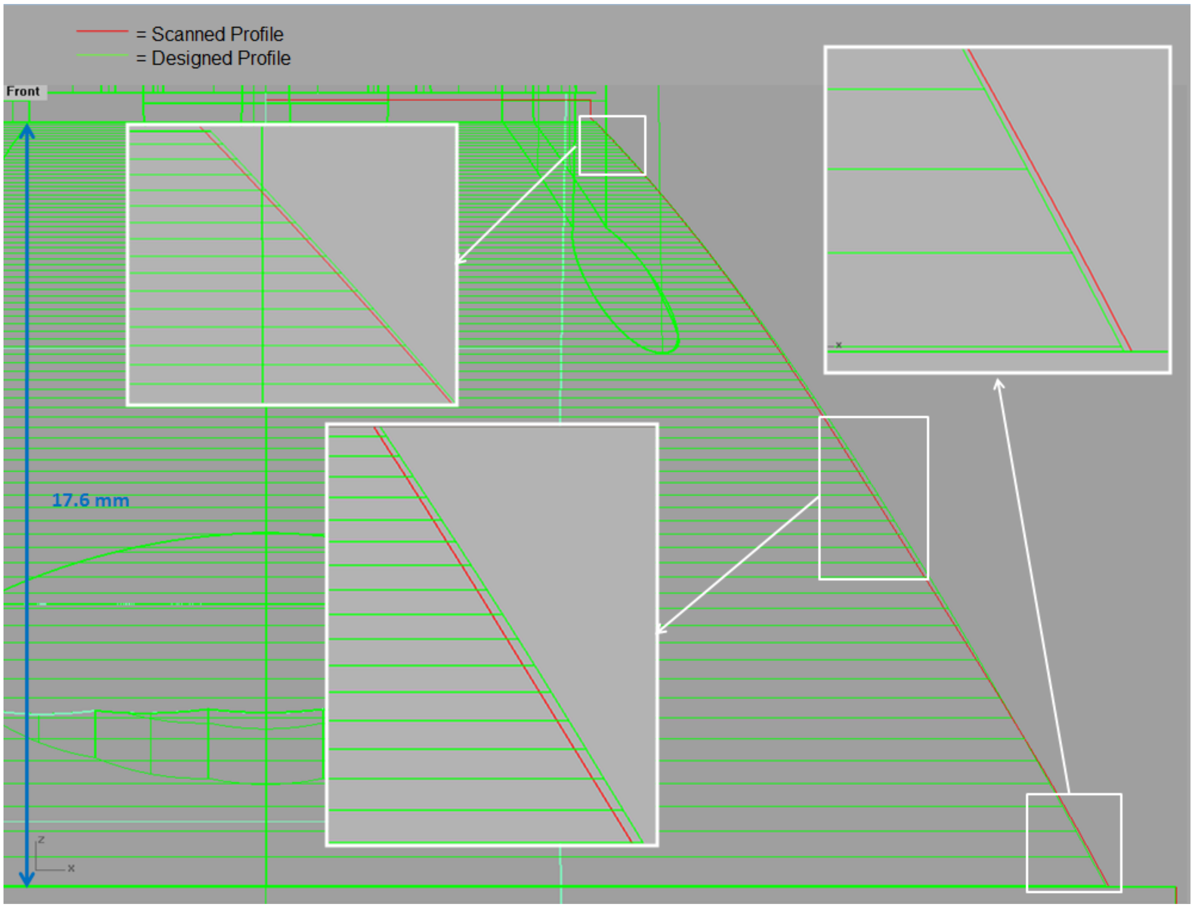

Figure 7: The measured profile shown in red was +/- 0.1mm from the design profile, shown in green. The change in surface normal was far more important than the offset distance, as the surface normal controls the reflected or refracted light direction produced by the optical part. In reflection, a 1° change in surface normal results in a 2° difference in the reflected light direction. As a reference, a 2° ray direction shift over the 750mm throw distance of this application results in a beam shift by about 25mm, a significant spread if the target is only 100mm tall.

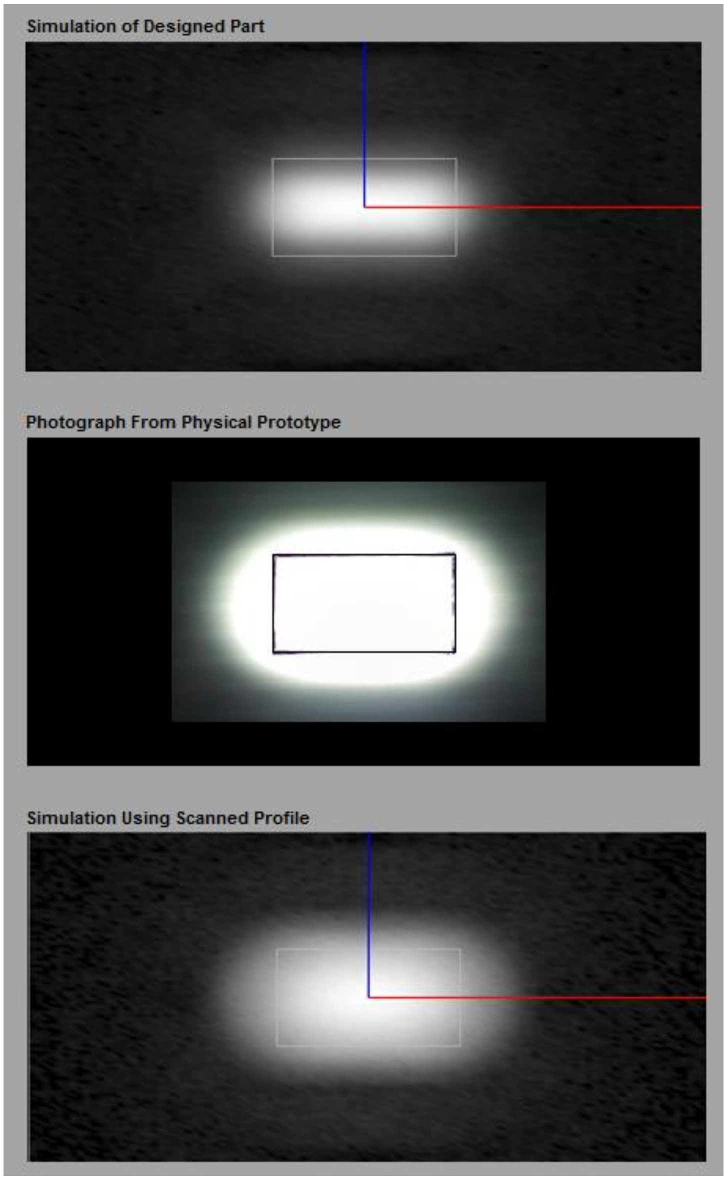

Figure 8: The simulated beam performance of the original design (top) showing the beam illuminance with respect to the rectangular target area, the obtained beam performance of the first physical lens prototypes (middle) and the simulated beam performance of the lens using the measured TIR lens profile (bottom).

## Conclusion:

These examples illustrate the importance of parameters including light source geometry and optical part geometry. These are just 2 of the many factors listed above, but the results show that respecting these factors can lead to more accurate simulation results. The limit of acceptable optical part tolerances can also be predicted, but the challenge is knowing just how the physical parts will vary from the design geometry. That's a function of several factors including the manufacturing method, tooling process and materials used.