

# Photometric File Representation for Non-Standard Luminaire Shapes

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## **Abstract:**

Luminaire performance needs to be accurately modeled in software simulations for lighting designers to confirm their design requirements. This demands both accurate luminous intensity distributions as well as accurate luminous geometry. This paper addresses the luminous geometry. Due to a combination in the limits for how luminous geometry can be defined in standard photometric files as well as how that geometry is treated in lighting design software, the luminous geometry is generally limited to a homogenous rectangular box. The more the actual luminous geometry strays from this assumption, the larger the potential error in the simulation results. This paper presents a method to improve how luminous geometry is represented by defining the photometry and geometry for a small section of a luminaire to be used as a building block for creating non-rectangular and non-homogenous shapes. This method has been applied to ring luminaire pendants of 2 sizes, which along with other curved shapes enabled by LEDs, are becoming more popular and stray far from the rectangular box assumption. The amount of error that can result from modeling these devices with simplified geometry and modeling them with an array of small sections is shown.

## **Background:**

As part of the design phase for an architectural space, luminaires and room geometry are typically modeled in programs such as AGI32, DIALux or Visual in order to create realistic renderings and/or calculate various photometrics in the space. IES and Eulumdat (LDT) files are universally used for luminaire modeling in these programs, as they include photometric data of a particular luminaire. Luminous dimension specifications are included in the IES and LDT file data as length, width, and depth, making it simple to represent any rectangular luminous shape. IES and LDT file formats also allow round (cylindrical/ellipsoidal) luminous shapes to be

represented by changing the sign of the length, width, and depth values (IESNA, 2002) (Helios32, 2009).

IES and LDT files represent luminaire distributions through a set of luminous intensity values, which are assumed to be far-field data. In standard photometric practice, far-field data should be restricted by the “five times rule,” which says that illuminance calculations are considered acceptably accurate at distances that are at least five times greater than the greatest luminous dimension of the luminaire (DiLaura, et al., 2011).

### **Problem:**

Using IES/LDT files to model luminaires in lighting design software, there is no direct way to represent a luminous shape that is not homogenous. One common example that is not covered is a ring shaped luminaire, such as the direct/indirect pendant shown in Figure 1.



*Figure 1: Ring luminaire product, Doppio from Sattler Lighting [Source: <http://www.sattler-lighting.com/en/portfolio/doppio-2/> (10/03/2018)]*

Representing this luminaire's luminous shape as a circle in an IES/LDT file results in a luminous area that homogeneously fills in the entire area of the circle. In other words, the model will be evenly emitting light from all areas within the circle, including the area in the center of the ring where there is no light source and no luminous surface. Furthermore, most lighting design software will model the defined luminous area as square rather than circular.

Figure 2 shows a 5' diameter luminaire model created in the Photopia optical modeling software, which includes the actual luminaire geometry along with the appropriate LEDs, reflector and diffuser materials, in order to generate photometric data including an IES file. Since the Photopia model includes the actual luminous geometry along with any inhomogeneities of the light within that geometry, it is capable of predicting accurate near-field effects on nearby surfaces. This is illustrated in Figure 3 with an illuminance plane 1' above the luminaire. The IES file generated from the Photopia model of the complete luminaire is then imported into lighting design software, as shown in Figure 4. Figure 5 & 6 show the results from running this IES file in both AGI32 and Visual. Comparing these to Figure 3, it is apparent that the IES file for the complete luminaire does not accurately reproduce the results seen when modeling the actual luminous geometry.

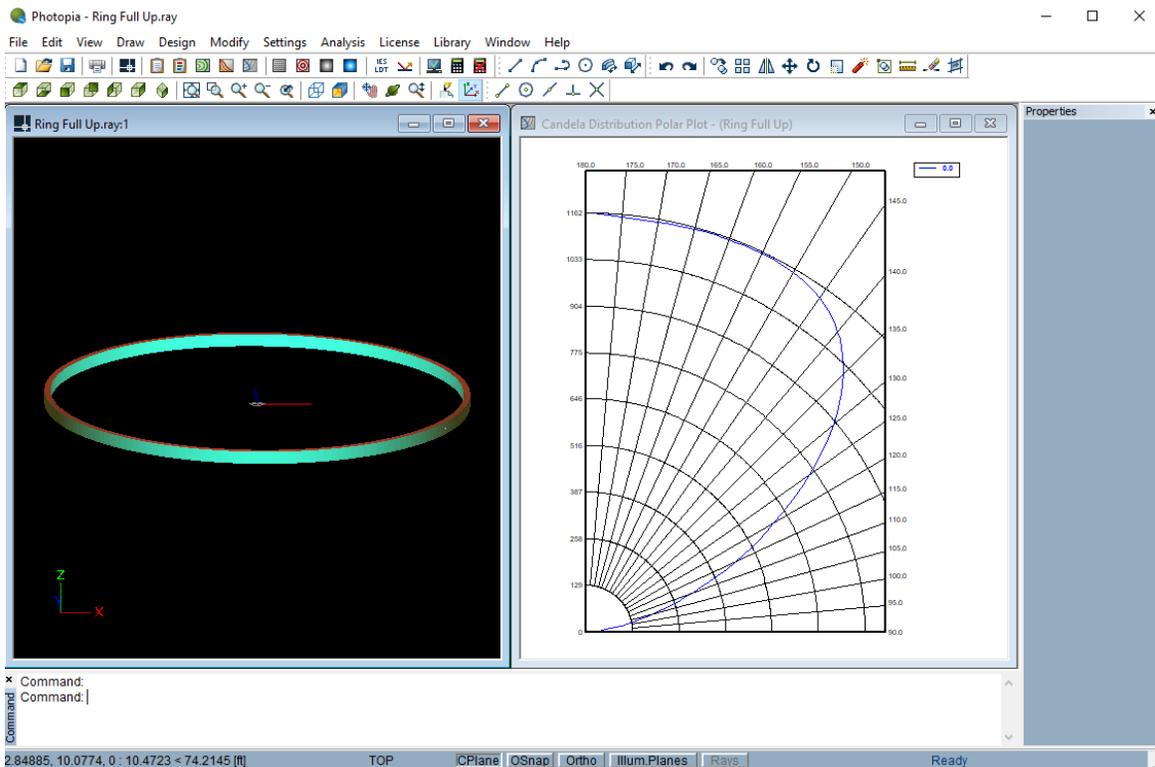


Figure 2: Luminous geometry model of 5' ring indirect luminaire example created to generate an IES file. [Photopia, LTI Optics]

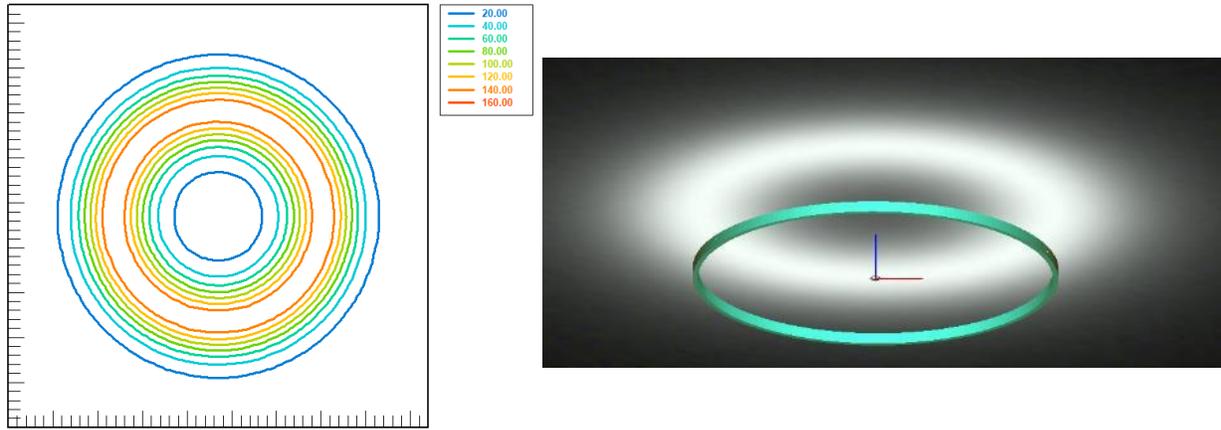


Figure 3: In Photopia, the analysis of an illuminance plane at 1' above the 5' ring luminaire. [Photopia, LTI Optics]

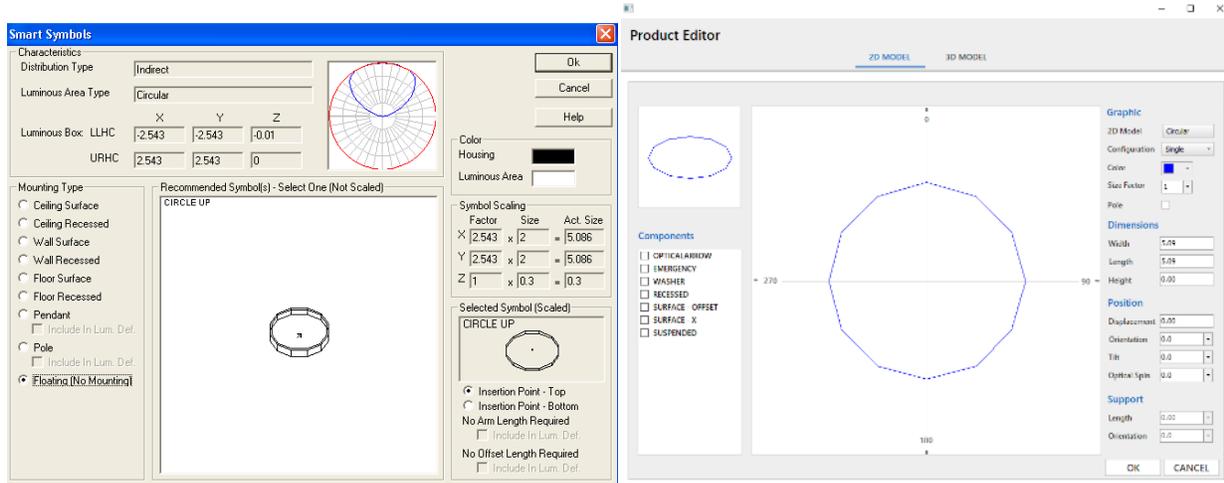


Figure 4: The IES file for the full ring is then imported into lighting design software for modeling in a room. The luminous area is represented by a polygonal area in the visual display, but in photometric modeling is represented by a zero-reflectance rectangular area; it is not represented by a ring. [Left: AGI32, Lighting Analysts. Right: Visual, Acuity Brands]

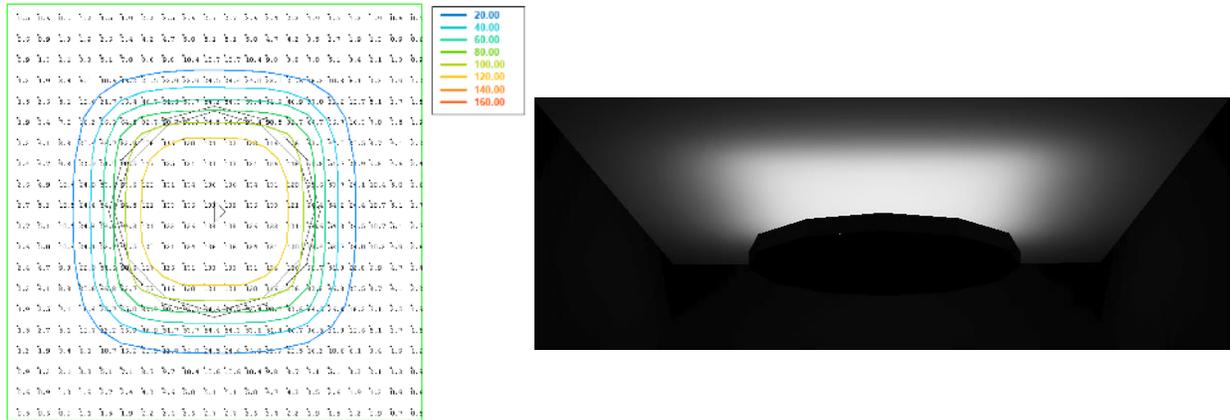


Figure 5: In AGI32, illuminance values in footcandles show an increase in illuminance above the center of the 5' ring at 1' above. The illuminance pattern is square. Note that the black polygon outline represents the luminaire geometry defined in the IES file. [AGI32, Lighting Analysts]

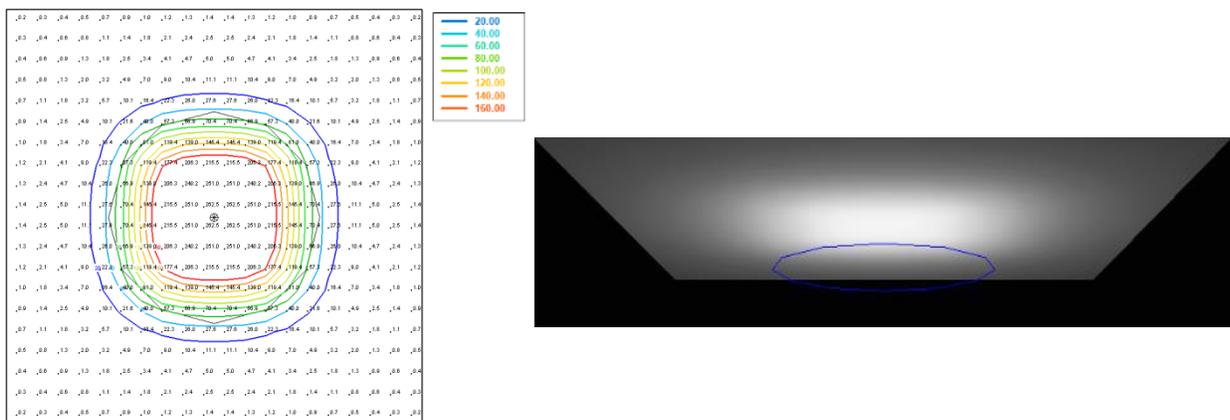


Figure 6: In Visual, illuminance values in footcandles show an increase in illuminance above the center of the 5' ring at 1' above. The illuminance pattern is square. Note that the black/blue polygon outline represents the luminaire geometry defined in the IES file. [Visual, Acuity Brands]

To further clarify how the luminous geometry is treated in AGI32 and Visual, we've confirmed that both programs approximate circular & elliptical luminaire shapes with a rectangular box. For the case of a circular area, AGI32 uses the luminaire diameter defined in the IES file as the side lengths of a square (Spahn, 2018). Visual defines a square size with an equivalent area to the circular area defined in the IES file. This results in square side lengths that are about 89% of the diameter (DiLaura, 2018). Both programs have methods of dealing with luminous areas that are close to nearby surfaces and violate the five times rule. AGI32 subdivides the luminous area into smaller sections that all satisfy the five times rule. Visual uses a contour integration

technique that allows for accurate near field illuminance predictions while maintaining the assumption of a homogenous emitting surface. Both programs appropriately transform the luminous area as luminaires are aimed. Any luminous shape that is not rectangular or circular will be hindered by the luminous area restrictions. Another example of a non-standard luminous shape is shown in Figure 7. This application shows a reception office setting, an example for which specific light level recommendations are required in standard design practice (DiLaura, et al., 2011).



*Figure 7: A luminaire with a unique shaped luminous area, Freedom from Fagerhult [Source: <https://www.fagerhult.com/Products/freedom/freedom/> (10/03/2018)]*

Another significant and probably more important consequence of the simplified luminous geometry is its effect on the horizontal illuminance under the luminaire. Light in the wrong location on the ceiling is one problem, but a larger problem is that the luminaire luminous geometry also blocks light during interreflected calculations in both AGI32 and Visual (Spahn, 2018) (DiLaura, 2018). This means the large square surface is blocking the brightest part of the ceiling, resulting in lower than expected illuminance values below the luminaire. To illustrate this effect, simulations were created with a diffuse ceiling above the indirect ring luminaire

pendants to analyze the work plane below (Figure 8 and Tables 1-2). Comparing results from Photopia that uses the actual luminous geometry to results in AGI32 and Visual that use the IES file representing the entire luminaire, it is shown that the illuminance values are significantly lower than expected in AGI32 and Visual. This is a problem since it means more lumens and thus more watts will be specified in the luminaires or more luminaires will be installed to meet required light levels. This in turn means higher costs for equipment, installation and electricity over time.

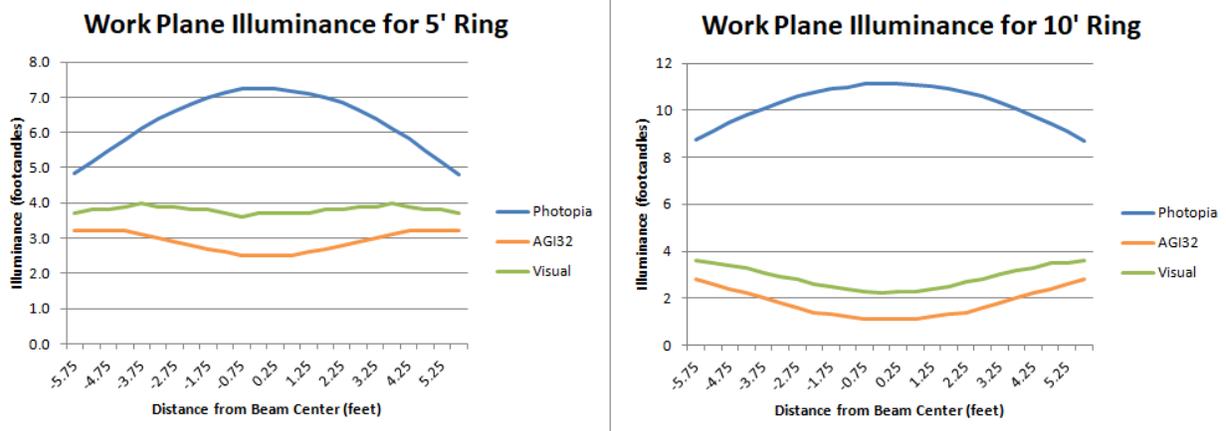


Figure 8: Illuminance through the center of a work plane below the luminaire, for a 5' diameter ring luminaire (left) and a 10' diameter ring luminaire (right). Assumptions include: luminaire is mounted 2.5' below a diffuse 80% reflective ceiling, work plane is 7' below the luminaire, calculation points spaced 0.5'x0.5' over a 12'x12' area, walls and floor are not included in simulations to isolate the effect of light reflected from the ceiling to the work plane.

Table 1: 5' Diameter Ring Average Work Plane Illuminance

Simulation Software	Average Work Plane Illuminance	Relative Average Work Plane Illuminance
<b>Photopia</b> (actual luminous geometry)	5.52 fc	100%
<b>AGI32</b> (IES file)	3.06 fc	55%
<b>Visual</b> (IES file)	3.7 fc	67%

Illuminance averages on a work plane below the luminaire for a 5' diameter ring luminaire. Assumptions include: luminaire is mounted 2.5' below a diffuse 80% reflective ceiling, work plane is 7' below the luminaire, calculation points spaced 0.5'x0.5' over a 12'x12' area, walls and floor are not included in simulations to isolate the effect of light reflected from the ceiling to the work plane.

*Table 2: 10' Diameter Ring Average Work Plane Illuminance*

Simulation Software	Average Work Plane Illuminance	Relative Average Work Plane Illuminance
<b>Photopia</b> (actual luminous geometry)	9.39 fc	100%
<b>AGI32</b> (IES file)	2.31 fc	25%
<b>Visual</b> (IES file)	3.2 fc	34%

*Illuminance averages on a work plane below the luminaire for a 10' diameter ring luminaire. Assumptions include: luminaire is mounted 2.5' below a diffuse 80% reflective ceiling, work plane is 7' below the luminaire, calculation points spaced 0.5'x0.5' over a 12'x12' area, walls and floor are not included in simulations to isolate the effect of light reflected from the ceiling to the work plane.*

The average work plane illuminance ranges from 33% to 75% below what is expected for these particular scenarios. As described above, the smaller square luminous area in Visual explains why there is less shadowing and thus higher work plane illuminances in these comparisons. The amount of error caused by inaccurate luminous areas will of course vary depending on the luminaire details and how they are employed in a room, but this study does confirm how significant of a problem it can become. Since accurate modeling is necessary to effectively develop the most efficient design that meets the project requirements, the designer can't rely on the simulated results for these types of luminaires unless the modeling is done differently.

AGI32 does provide an option to create a custom luminaire symbol and the geometry for this symbol can be constructed to approximate the ring shape. If this is done and if the symbol type is set to "Model and Render," then the symbol geometry will be used as the occluding geometry during the interreflected calculations. This would significantly improve these results since the brightest part of the ceiling would no longer be shadowed by the large square, however the symbol geometry is not used for the direct illuminance calculations. So the direct light on the ceiling would still show a square shape rather than the ring shape. Viewing a rendering of that light on the ceiling above the ring shaped luminaire would clearly show a disconnect in luminaire geometry used for different purposes.

Simulations done in DIALux showed these same trends of using a square luminous area for the direct lighting calculations and that luminous area shadowing interreflected light. Detailed results for DIALux were not included since they included some unexplained asymmetries on the work plane.

## Recommended Solution:

A more accurate way to model non-standard luminous shapes while still using the convenience of a standard photometric file is to section the shape into parts, using a rectangular representation for each section. For this study, the example ring luminaire is divided into 36 equivalent parts, such that a 36-sided polygon represents the shape of the round ring. Figure 9 shows the Photopia model of a 1/36<sup>th</sup> section of the ring luminaire. The ends of the luminaire are assigned a 100% reflective specular material, so the output of this section will include the effects of LEDs on either side that contribute light to this section in the full luminaire. In a physical test, the end reflectors should use a material as close to this as possible, such as Alanod Miro 4 (95%) or Alanod Miro 4 Silver (98%).

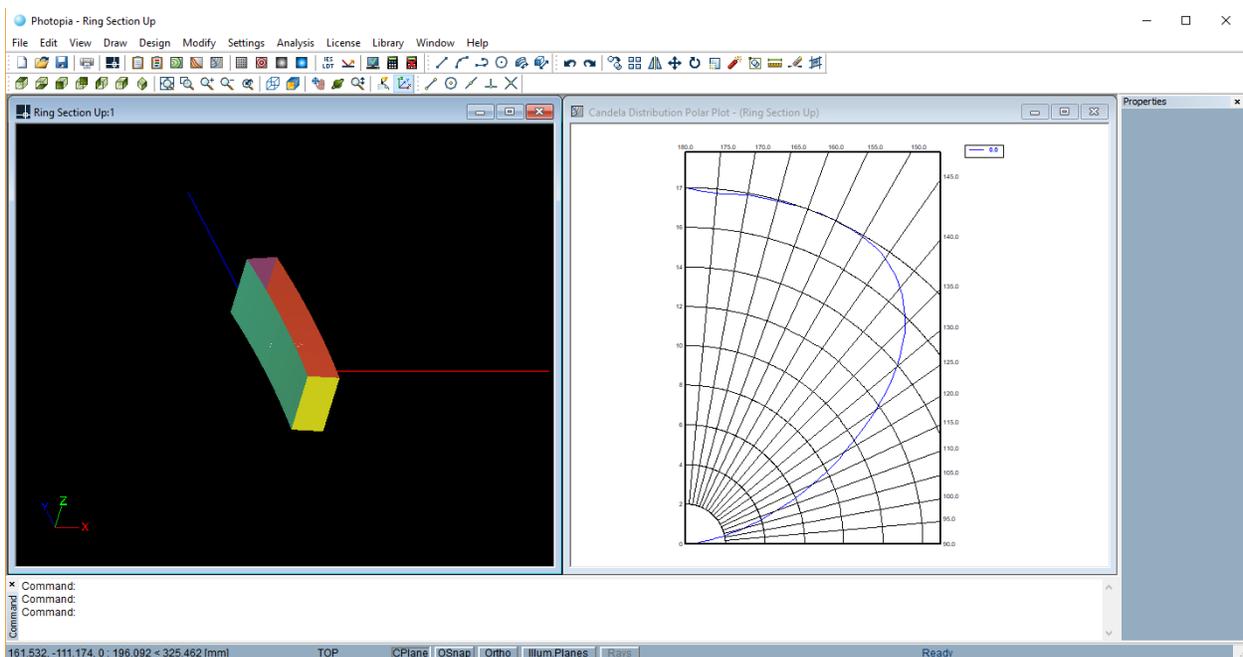


Figure 9: Model of a 1/36<sup>th</sup> section of ring indirect luminaire example created to generate an IES file. Each end of the section (where the luminaire would continue) is modeled as perfectly specular and 100% reflective, to best represent the distribution of the continuing luminaire. [Photopia, LTI Optics]

Dividing the luminous area into more or less parts will give a higher or lower resolution model. The required resolution of the geometric approximation will depend on the shape of the luminaire on how it is used in a project, but this example provides one reference for how well this resolution can work.

The sectioning process results in a significantly more accurate simulation, as shown in Figures 11-12 and Tables 3-4.

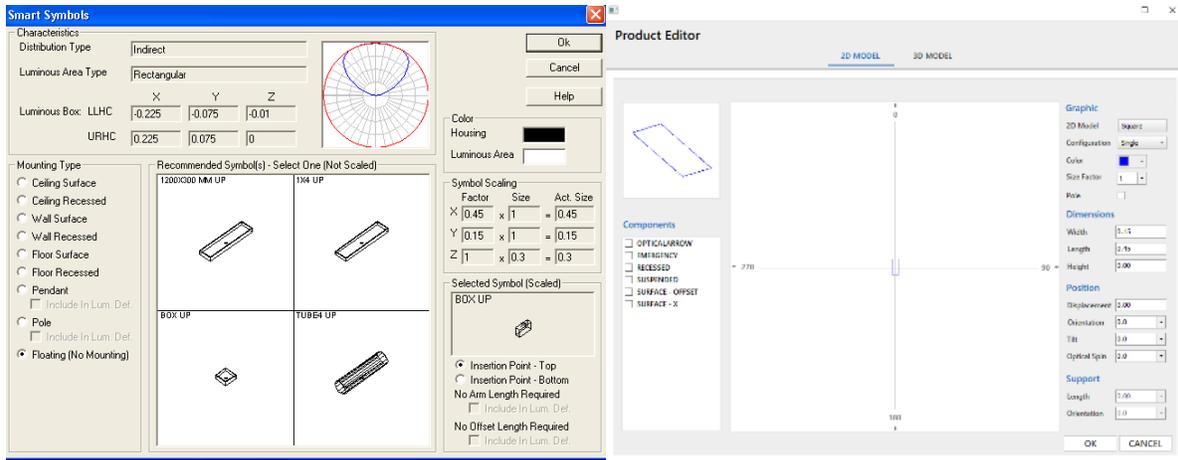


Figure 10: The resulting IES file of the section is imported into lighting design software for illuminance modeling. The complete luminous area is represented by multiple rectangular sections, one of which is shown here for each program. [Left: AGI32, Lighting Analysts. Right: Visual, Acuity Brands]

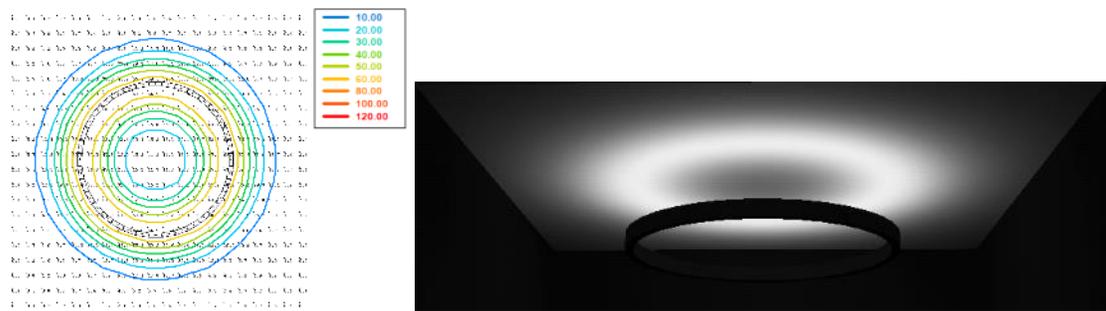


Figure 11: In AGI32, illuminance values in footcandles & ceiling rendering show a dip in illuminance at 1' above center of the 5' ring, more similar to the Photopia analysis of actual luminous geometry (Figure 3). Note that the black outline represents the polar array of the section models. [AGI32, Lighting Analysts]

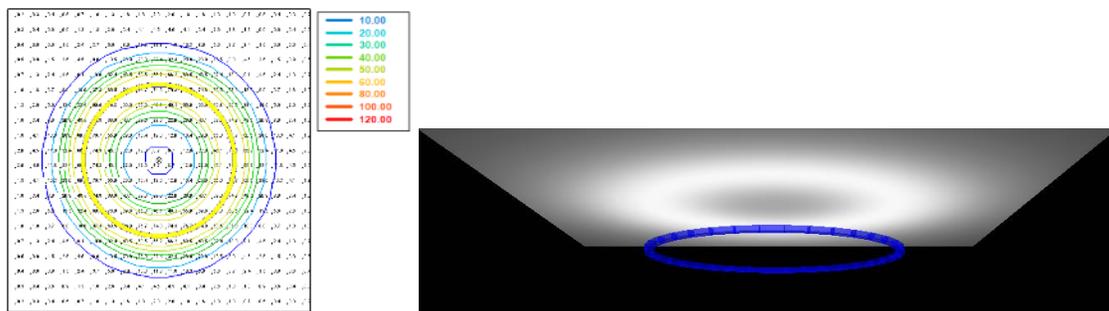


Figure 12: In Visual, illuminance values in footcandles & ceiling rendering show a dip in illuminance at 1' above center of the 5' ring, more similar to the Photopia analysis of actual luminous geometry (Figure 3). Note that the thick yellow/blue band represents the polar array of the section models. [Visual, Acuity Brands]

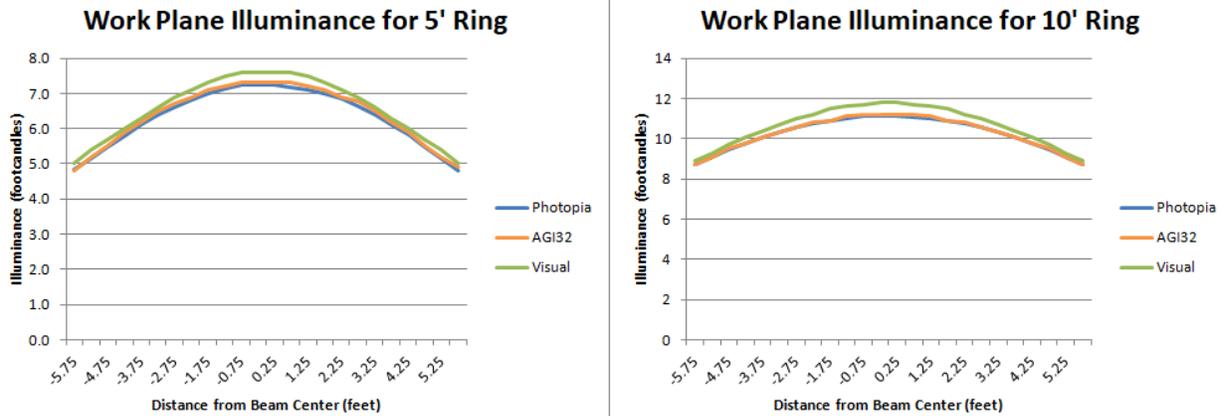


Figure 13: Illuminance values through the center of a work plane below the luminaire, for a 5' diameter ring luminaire (left) and a 10' diameter ring luminaire (right), now using sectioned IES files in AGI32 and Visual. Assumptions include: luminaire is mounted 2.5' below a diffuse 80% reflective ceiling, work plane is 7' below the luminaire, calculation points spaced 0.5'x0.5' over a 12'x12' area, walls and floor are not included in simulations.

Table 3: 5' Diameter Ring Average Work Plane Illuminance, Using Sectioned IES Files

Simulation Software	Average Work Plane Illuminance	Relative Average Work Plane Illuminance
<b>Photopia</b> (actual luminous geometry)	5.52 fc	100%
<b>AGI32</b> (sectioned IES files)	5.56 fc	101%
<b>Visual</b> (sectioned IES files)	5.7 fc	103%

Illuminance averages on a work plane below the luminaire for a 5' diameter ring luminaire, now using sectioned IES files in AGI32 and Visual. Assumptions include: luminaire is mounted 2.5' below a diffuse 80% reflective ceiling, work plane is 7' below the luminaire, calculation points spaced 0.5'x0.5' over a 12'x12' area, walls and floor are not included in simulations to isolate the effect of light reflected from the ceiling to the work plane.

Table 4: 10' Diameter Ring Average Work Plane Illuminance, Using Sectioned IES Files

Simulation Software	Average Work Plane Illuminance	Relative Average Work Plane Illuminance
<b>Photopia</b> (actual luminous geometry)	9.39 fc	100%
<b>AGI32</b> (sectioned IES files)	9.40 fc	100%
<b>Visual</b> (sectioned IES files)	9.7 fc	103%

Illuminance averages on a work plane below the luminaire for a 10' diameter ring luminaire, now using sectioned IES files in AGI32 and Visual. Assumptions include: luminaire is mounted 2.5' below a diffuse 80% reflective ceiling, work plane is 7' below the luminaire, calculation points spaced 0.5'x0.5' over a 12'x12' area, walls and floor are not included in simulations to isolate the effect of light reflected from the ceiling to the work plane.

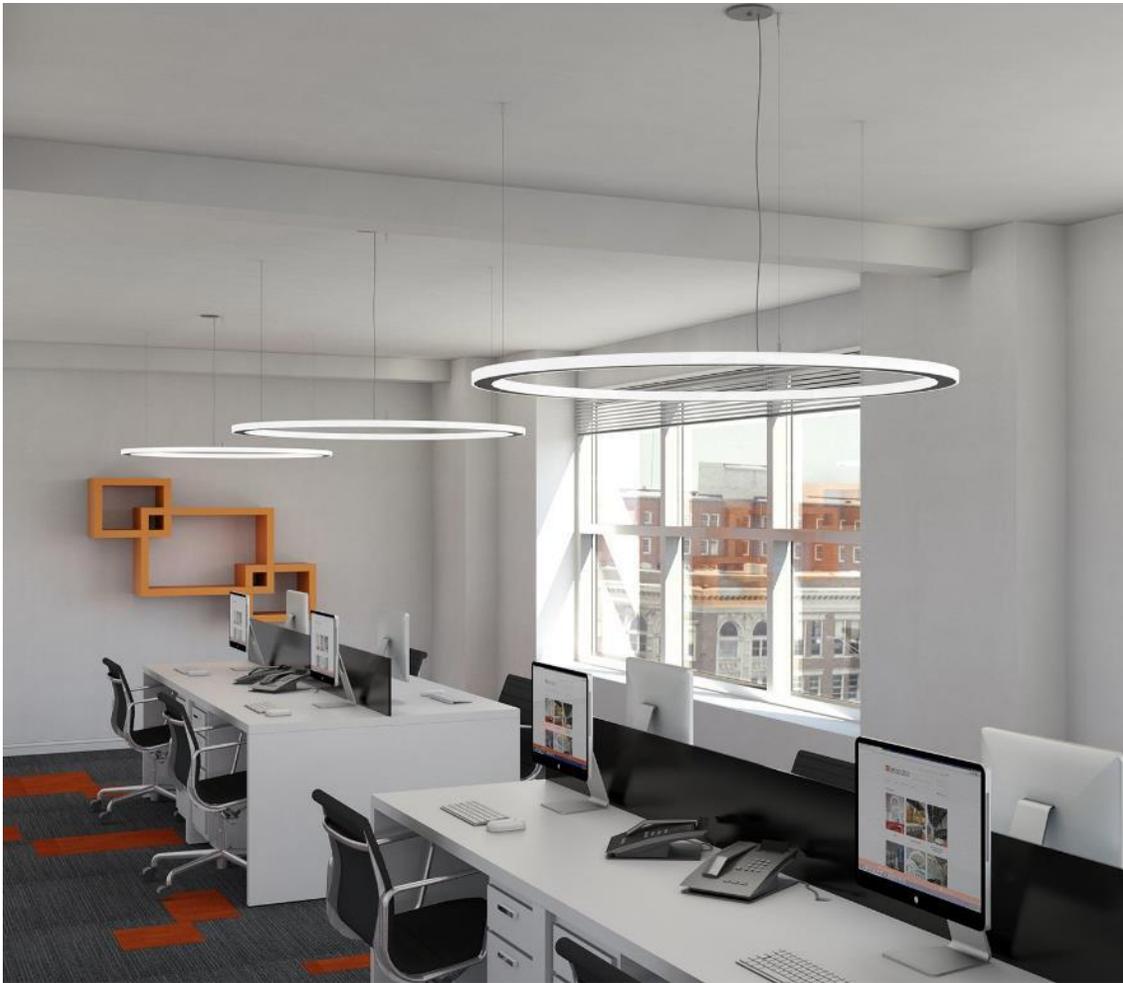
These results show that the average horizontal illuminance is now within 3% for all 3 programs, a marked improvement and confirmation that given better input data for luminaires, the lighting design software can produce more accurate results.

When asked to generate a photometric report for a ring luminaire, labs such as Independent Testing Laboratories, Inc. (ITL) discuss this limitation of how the luminous geometry will be represented and generally recommend that a section of the luminaire be measured instead of the entire device (Bergin, 2018). This is the only way larger luminaires that are beyond the size limitations of the goniophotometers can in fact be physically measured. Smaller products that can fit on the goniophotometer can be measured as a whole, but will not accurately show how the luminaire performs in a room if it is represented by a single IES/LDT file.

To make the process of modeling non-standard luminaire shapes easier in lighting design software, manufacturers could work to distribute pre-built components that utilize this process. The other option is to push for an expansion to how luminous geometry is defined in IES/LDT files so that it is flexible enough to handle any arbitrary luminaire shape and non-homogeneity across the luminous surfaces.

## Further Examples:

There are many other examples of luminaire shapes that are not easily represented by a single IES/LDT file. Two more example products are shown here.



*Figure 14: The Micro Ring DE luminaire from Beta Calco is an example of a ring luminaire with luminous sides, which cannot be represented by the luminous dimension options within an IES file. There is no way to define that only the sides of the box emit the light. So a 1/36<sup>th</sup> section that represents the outward emitting light, for instance, may be constructed as a downward directed light, then rotated so that the light is emitting to the side, and then arrayed into the complete ring shape for the outer luminous surface. The inner luminous surface can be treated in the same way and arrayed in an appropriate offset location from the outer luminous surface. [Source: <https://betacalco.com/products/micro-ring-de/configuration> (11/26/18)]*



*Figure 15: The Calumet luminaire from Artemide is an example of a luminaire with a separate luminous top and bottom, which cannot be represented accurately with a single IES file model because the luminous area cannot be defined to represent 2 emitting surfaces separated by non-luminous sides. This luminaire should be represented by two separate photometric files, one for the uplight and one for the downlight. [Source: <https://www.artemide.com/en/products/outdoor#> (11/26/18)]*

## **Conclusion:**

The accuracy of lighting design software is limited by the accuracy of the luminaire photometric data, including the luminous area. This paper shows just how much of an effect the luminous area can have on the simulated lighting levels in a room. It also shows that simulation results can be significantly improved when using the recommended method of building non-standard luminaire shapes from sub-sections of the overall device. Until standard photometric files can represent more arbitrary luminous geometry, the recommended method does allow lighting designers to get more accurate simulations and thus produce the most cost effective and energy efficient designs.

## **Disclosure:**

The authors are associated with LTI Optics, which develops Photopia.

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## **Biographies:**

**Meg Tidd** is a Senior Optical Engineer at LTI Optics, where she primarily provides optical design consulting services to various manufacturers for a wide range of lighting and other non-imaging optical applications. Her background includes a lighting design undergraduate education in Architectural Engineering at the University of Colorado, Boulder, and she is currently pursuing a Master's in Optical Science at the University of Arizona, Tucson.

**Mark Jongewaard** is President of LTI Optics. He has managed Photopia's development since its inception and has extensive experience in non-imaging optical design & training as well as material & light source measurements and modeling. He holds BS & MS degrees from the University of Colorado, Boulder and has been teaching a full semester class for illumination optical design at CU since 2009. Additionally, he serves on the board and teaches the optical design and photometry sessions at the Rocky Mountain Lighting Academy (RMLA), a continuing education program CU offers to the lighting industry. He also serves on the board of the Council for Optical Radiation Measurements (CORM).

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