

# Photometric and photorealistic representation of luminaires in 3D software

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## 1. Introduction

The continuous increase of the computational power (faster results) of today's computer contributed to the diffusion of 3D representation software used by designers to produce the so-called photo realistic renderings. The goal of these images, usually, is to show what should be the final look of the project.

Very often, unfortunately, these representations are the result of empirical graphic representation based (in the best cases) on the experience of the designer and his ability to achieve images that are similar to what he plan to realize. However, when these forecast images are produced without a precise methodology in the management of virtual materials or the importing and integration of technical data of lighting products, the resulting digital images, although their strong visual impact, do not match the final appearance of the project once put in place.

Having a beautiful image to present to the clients may help the designer to get the job, but in the end, if the real scene (with all of its luminaires, finishes and materials) is too different from the virtual image presented, there can be problems with the clients.

This paper is part of a more wide work on representation and is meant as a help for the designers, by using modelling and representation techniques that are quick, efficient and that suit better the typology of selected lighting fixture. Our aim is to describe some accurate and practical techniques of modeling and representation of the lighting fixtures in a virtual project, while maintaining both photo-realism and photometric accuracy.

These procedures can be used in the most common 3D software (for modelling and representation).

## 2. Modeling

Often the designer, in order to speed up the modeling process, makes use of 3D models available online from the manufacturer's website or portal/libraries dedicated to three-dimensional computer graphics.

Unfortunately, these models are not always suitable for the production of forecast images, for various reasons. Some time they are conversion of models that have been created for the CNC (Computer Numerical Control) of the objects, so with the purpose of the realization of a physical model; or maybe with a different setting of the coordinates system. This can result in the first case in a model with excessively many polygons and in the latter, a model that can have "inverted Normals" (that result in visible "holes" in the surfaces of the objects).

In these cases the better choice is to rebuild the model of the luminaire, defining from the beginning the desired level of detail and therefore the modelling technique that allows the designer to obtain a good result and in an efficient way, by thinking to the final rendering from the beginning.

The level of detail is fundamental in order to not wasting time, needed for modelling (user time) and for the rendering (computational time). The designer must be aware whether the luminaire will be represented in the foreground, the background or in an intermediate situation. In the latter case, the modelling techniques used, have to allow changes in the resolution of the 3D model, increasing the resolution (and thus the quality and the computational time required) of the geometry in relation to the importance of the model in the scene (using for instance the subdivision modelling).

The choice of the best modelling technique depends from the geometry of the luminaire that can be made of one single piece or by multiple components (in this case, the techniques can be more than one). If the model can be assimilated to basic geometries, it will be enough to use the CSG (Constructive Solid Geometry) modelling. The primitives available in the software (cubes, spheres, cylinders, cones, toroid, etc.) are edited with basic transformations such as move, rotate, scale or copy.

If the model turns out to be more complex, but still can be built with operations of addition, subtraction or intersection between two or more solids, it is possible to use the so-called Boolean operations. These are very fast in order to obtain complex geometries even if they can cause two order of problems: visual continuity between the polygons (strange shadows and colors) and topology (the organization of the polygonal structure) of the model. In the most common modelling software there are tools that allow to solve (or at least to improve) these problems.

The modelling based on 2D shapes is ideal in case of long (more or less flat) thick objects, so extrusion or taper operations can be effective.

Many lighting fixtures can be assimilated to 2D profiles that can be revolved around a specific axis. The “lathe” command, present in most of the modeling software, may allow the designer to obtain these geometries easily.

For parts such as cables, filaments, springs, it is possible to use modeling tools such as Sweep or Loft [1].

Sweep allows the creation of 3D geometries by making a profile (generated by the user or available on a library) “run” along a path (always generated by the user) keeping its perpendicular aligned to the tangent of the path

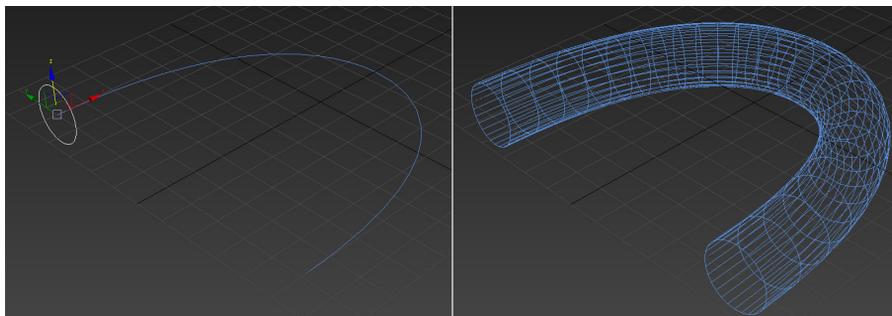


Fig. 1 – Example of the use of the Sweep tool. On the right, it is possible to see the circle that will act as profile running on the path (in this case a curve). On the left the resulting geometry.

The operation done by the Loft tool is similar to the one of the Sweep tool, but with more options. It is possible to scale, rotate or twist the profile, along the path,

modifying the resulting geometry. If no one of the previous tools can be used efficiently, the modelling technique that allow the designer to reproduce the most complex shapes is the Polygonal modelling [2].

Generally, starting from images (most likely technical drawings, the “blueprints”) used as planes of projection; it is possible to start from a primitive solid (or a single polygon) and rebuild the entire object (by moving and/or adding vertices and polygons). It is good practice to begin realizing a low-poly model (when possible) and then increasing the number of polygons at will, by using a “Subdivision tool”. This procedure split up the interested polygons in four parts and (if present) relax the adjacent polygons (also divided) creating a more smooth geometry. The process can be repeated more times intervening on a single parameter (number of iterations). However, it is necessary to pay attention to the number of iterations selected, because for each one, the number of polygon of the interested area quadruplicates, increasing exponentially the weight of the 3D model and the time needed to calculate the renders.

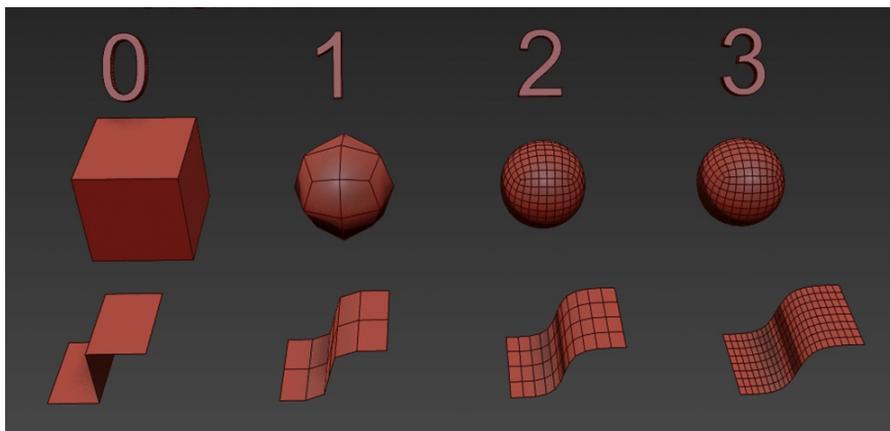


Fig. 2 – Example of increase in the number of polygons in relation to the number of iterations choices for the object.

In order to decide how many iteration are needed for a model, as previously mentioned, the designer should know the importance of the object in the scene; for foreground objects, the number of iterations will be much greater than for objects in the background.

### 3. Photometry

Once achieved the goal of a balanced (quality/weight) 3D model, it is necessary to transform the obtained geometry into a luminaire that can be used to render the final scene.

A desirable thing is to use the software as a verification tool (how my project will look like, if I choose one luminaire instead of another) and not just to produce attractive images. In order to do so, it is necessary that the software in use is equipped with calculation algorithms that approximate the real light distribution in space, in a plausible manner. This is possible only when indirect light is actually calculated by the interaction of the emitted light and the surfaces of the scene, and

not simulated with hypothetic parameters such as “ambient light” (used in some software to increase the amount of diffused light in the scene).

In the past (in software used to do lighting verification), these calculations were made by the algorithms of Radiosity (which allowed the simulation of light diffused evenly in all the directions and the soft shadows) and integrated by Ray tracing algorithms (used to calculate specular reflections and sharp, defined shadows). Nowadays, the programs specialized in light calculations have been updated with more recent algorithms such as Photon mapping (frequently available also on common modelling and representation software) or the rapidly diffusing Physically based render.

That said it must be clear to the designer that it is not possible to get reliable results by using the typical (found in every representation software) light sources of computer graphics (such as OpenGL Ambient, Point, Directional, Spot).

The real luminaires have (in most cases) a spatial distribution of intensity more complex than these defined by OpenGL lights. As an example, it is very easy to understand that the light distribution in space of a road luminaire is not similar to that of a table lamp or a spotlight (used for example in a retail premise). Each luminaire has a real light distribution, which is the result of interaction between the lamp (commonly called "bulb") and the optical system of the device, generally designed to meet specific project requirements.

### 3.1. Photometric files

The "shape of emission" of light in luminaires is generally measured by using an instrument called Goniophotometer that performs an angular investigation on the emission and saves the results in ASCII files containing (along with other parameters) a table that put in relation spatial angles with the light intensity emitted by the luminaire. These files are generally called Photometric files, or Photometric webs.

Obviously, these shapes are more complex than the OpenGL lights (that are not able to imitate these shapes).

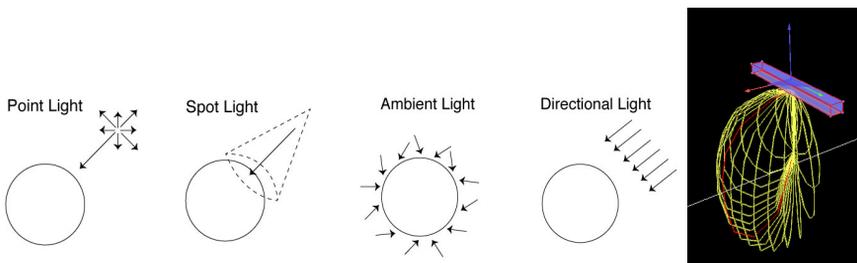


Fig. 3 – From left to right, different generic light sources commonly used in 3D softwares: Point, Spot, Ambient and Directional. The far right shows the photometric web of a real lighting fixture (Mellow Light IV by Zumtobel)

The photometric files are generated in different formats (mostly in relation to the nation in which they are acquired/crated) such as Eulumdat - \*.ldt (mostly Europe) [3], IESNA - \*.ies (America) [4], CIBSE TM14 - \*.cib (United Kingdom) [5], LTLI - \*.ltl (Denmark) [6].

In addition to these standard files are also several proprietary formats used by specific lighting design software, such as the format \*.uld (Dial - Dialux) [7], the

format \*.oxl (Oxytech - Litestar) [8] or the format \*.rolfz (Relux Informatik - Relux) [9], which are often integrated with a 3D model that is usually given by the luminaire manufacturer (and not always modelled properly).

Obviously these latter formats are read only by their programs (whose main purpose is not the photorealistic rendering, but rather the photometric verification) and cannot be opened (photometric data + 3D model) with the software commonly used for photorealistic renderings.

The choice given to the designer is to import (in compatible software) the most common photometric files (such as Eulumdat) or other open formats (IESNA, CIBSE, LTLI) which can simulate the actual light distribution of the equipment, but still, not their physical appearance.

In order to reproduce the appearance of a luminaire it is necessary to couple the geometric model to its corresponding photometric web (usually recovered from the manufacturer or obtained by a relief in a laboratory).

### **3.2. Model and Photometry coupling**

After modelling the geometry of the luminaire with the methods suggested in paragraph 2, it is necessary to place a light source whose emission properties will be those of the photometric web. The photometric files are related to a point in space that emits light with different intensities as vectors in space.

In the physical reality, these intensities are the result of the interaction between the light emitted by the source (discharge in gas, burner, LED, etc.) and the optical system of the luminaire (reflector, refractor, lenses, filters, etc.) and, for this reason, the measured photometric file already considers these interactions.

Consequently, it is important that the three-dimensional model of the luminaire, does not interact (for instance, by cutting off) with the emission of the photometric web. In many software, this is possible by editing the properties of the light source so that some objects (in our case, the part of the luminaire that emits light, in which the photometric web will probably be placed) do not interact with the light (specifically, it does not cast shadows).

In order to complete this task correctly, the designer need to place the light source (photometric web) in a correct way according the modelled geometry. Logic would suggest placing the photometric web in the same position where the light source is found in the real luminaire. In reality, the solution is not so simple.

Where to place the photometric web (that is always assimilated to a point) when the light source is widespread? What is the placement position when, inside of the luminaire, there are multiple lights sources (such in the case of LED lighting fixtures)?

If the purpose is the photometric accuracy and the program allows you to exclude parts of the geometry from the lighting calculation, the correct position is that of the “photometric center” of the luminaire.

The photometric center is defined as the point where the luminaire is aligned with the measuring instrument (the goniophotometer) during the relief in which the photometric file is generated. The correct position of this point is described by the standards for the light fittings measurement, which may vary from country to country (for instance America [4] and Europe [6]) and result into the generation of different photometric files.

It is possible to consider the photometric center as the locus from which the light is emitted, and therefore, it should be considered as the point of junction between the geometry of the 3D model and the photometric files.

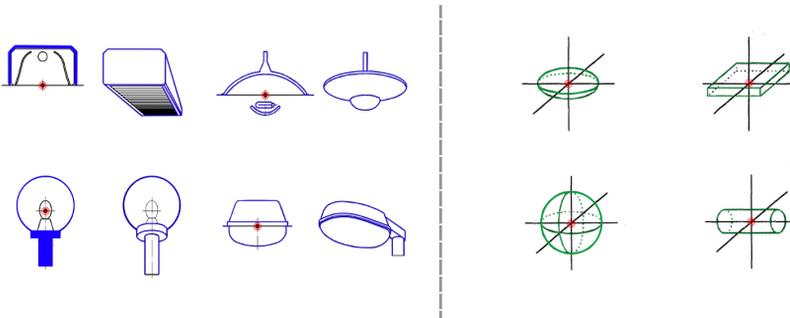


Fig. 4 – To the left (in blue) some guidelines for the identification of the photometric center (also called photometric zero), marked in red, as prescribed by the European standard UNI EN 13032-1. To the right (in green), some of the prescription provided by the American standard IESNA LM-63-02.

The operation of identification of the photometric center is easier for the categories described by the standard. Nevertheless, for some luminaires (mostly decorative) with very complex shapes, it is necessary to use some simplifications and adjustments (and this happens for the goniophotometric relief as well). For instance, a complex chandelier will hardly have a photometric file, but if the file exist, probably it will be not described in any standard. In this case, the designer should look at the shape of the photometric web, at the position of the light sources (by looking to a catalogue or the brochure of the product) and deduce the position of the photometric center that in most cases, correspond to the center of the geometry of the luminous part of the fixture.

#### 4. Color

A fundamental problem in the representation of the luminaires (and light in general) is constituted by the limits pf the representation devices. The computer-generated images are mostly produced to be displayed on video; it can also happen that these images are printed, maybe with high resolution but still, the means of typical representation, are unable to compete with the dynamic of the physical reality. This is true regarding both the luminance contrasts, and the spectral component of light. Having to use a representation device (usually a monitor), all of the colors must be converted to RGB triplets (Red, Green, Blue).

A mixture of three components does not compose light in physical reality; it is an electromagnetic radiation composed by different wavelengths of which, our visual system can perceive only the portion between 380 and 780 nanometers (so violet, indigo, blue, green, yellow, orange and red).

Given this, it is also necessary to specify that often, the light sources commonly used in luminaires, have nonlinear emission spectra (different form that of the sun, for example) but rather incomplete or in bands (peaks in certain colors). This is the reason why some light sources are less effective in render colors. Under these light sources, some colors appears to be dull and grayish.

The chromaticity of a computer generated light source, must necessarily be converted into an RGB triplet (to be represented common monitors, which are matrices of RGB LEDs), but also when the user have to decide the color of a light source within the modelling software, the most used method is still RGB.

Sometimes color presets are available in the interface (for example relating to different technologies or different color temperatures), but even if the chosen values recall the real physic, in practice, the light is colored only by changing the RGB values.

Nevertheless, there are some rendering programs [10] [11] [12] [13] [14] [15] [16] [17] [18] that implement algorithms able to mimic (more or less) the spectral behavior of light, displaying the color by simulating the spectral colors (with a given spectral step, for example simulating the properties with steps of 10nm).

There are many ways to implement these algorithms, but generally, although they allow higher accuracy in the calculation of color (simulating more correctly phenomena such as the spectral dispersion or the lower color-rendering index of some light sources), this cost globally in terms of greater complexity of use and extended computation times.

The same concepts are valid also for the materials applied (the so-called “shaders”) in the scene, which by reflection, refraction and transmission, can affect the spectrum of light by dispersion or by reflecting or transmitting only certain wavelength (and thus, changing the color of light).

If the will of the designer is to remain faithful to the physics of real world, it is necessary [19] to use a software that calculates light and its interaction with materials (shaders) with a full spectrum algorithm.

## **5. Case studies**

Three case studies of digital representation of real luminaires will be described below, but before starting, a little premise is necessary: the described techniques (modelling and rendering) are not the only ones that can be used. The focus is to achieve models that are clean, efficient and with a level of detail that can be increased or decreased at will.

The software used for this case studies is 3D Studio Max 2016 by Autodesk, but these techniques can be easily reproduced in any compatible modelling software.

### **5.1. Evoluzione by Disano illuminazione**

Evoluzione is a very common fluorescent linear lamp produced by Disano Illuminazione. The simple, straightforward design is also reflected on the simplicity of the modelling process. The luminaire is obtainable with five geometric shapes: a parallelepiped for the external shell, an extruded profile for the aluminum reflectors, cylinders for the lamps, other parallelepipeds for the lamp-holders and the side abutment.

The external shell is obtained by a parallelepiped, where on the lower face is visible a hole (obtained by subtraction of another parallelepiped). The thickness of the shell is obtained by using a command that create (with a given thickness) a series of polygons parallel to the existing ones (usually this command is indeed called “Shell”).

The profile of the reflector is extruded for the length of the luminaire, and closed at the sides, by the abutments, created by two parallelepipeds. These two elements are placed inside of the external shell.

The fluorescent lamps are obtained with four cylinders (primitives) while a polygonal modification of a parallelepiped, allow the designer to create the lamp holders.

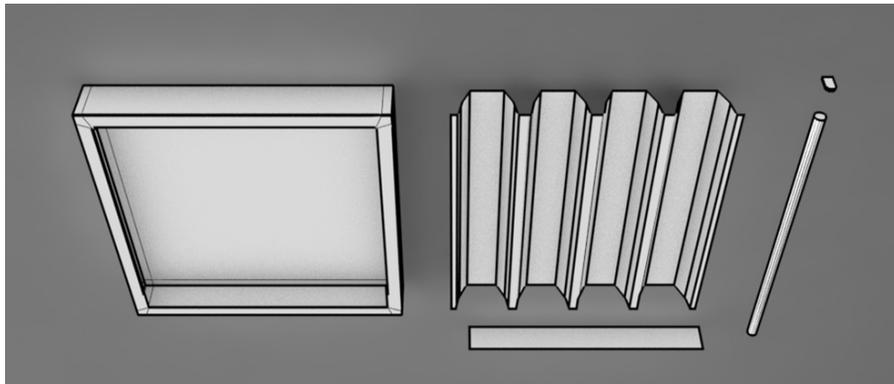


Fig. 5 – Basic geometric components for the 3D modelling of Evoluzione by Disano Illuminazione.

After the model is created, it is necessary to find the correct photometric file to couple with the model. As in most case, these files can be downloaded from the website of the manufacturer. To place the light source (photometric web) in the right position (photometric center) the designer should look at the standard. In this case, both the American [4] and European [6] standards states that the photometric center is in the center of the luminaire (intersection of median axes) at the height of the lower face of the external shell. It is important not to modify the values of intensity inherited by the photometric file, because these are the measured values of the luminaire.

The problem should be very visible right now: how it is possible to simulate the appearance of the four luminous tubes with just one photometric file (that, in this case, emits only downwards). Only with the photometric file, this is impossible. The tubes will appear dark, even if the luminaire is actually emitting. To solve this, the designer must use a little trick. First, it is necessary to assign the correct shaders to the geometry, paying attention to the energy balance of materials, because it is necessary to reproduce the real finishes (specular, diffused or combined reflections) and the right index of reflection (or transmission and refraction) of each part of the model. For Evoluzione, the external shell is a highly diffusive painted (white) metal with a small reflective component (around 65% diffusive and 5% reflective). The other parts (except the tubes) are made of brushed aluminum (70% specular with glossiness lowered to 50%).

To obtain the fluorescent tubes, it is necessary to use a self-illuminating material (many representation software possess this kind of shader) in order to simulate the light coming out from the tubes. Two important elements must be considered while using such material: first, the self-illumination effect must be visible in the reflections of the other components and second, the light emitted by the self-

illuminated material must be ignored in the global calculation of the scene. This because if the light of the self-illuminated material is computed, it will invalid the luminous emission of the photometric file, producing unrealistic results.



Fig. 6 – From left to right: picture of the luminaire, geometric model of the luminaire (red sign indicates the photometric center) and production render of the luminaire.

### **5.2. Caboche suspension by Foscarini**

The geometry of this luminaire is highly populated with elements that obviously, will affect the weight of the final scene. In order to create the “skeleton” of the object, a primitive can be used (in this case, a half-torus with a low number of polygons) and replicate in a roto-symmetric way. The refracting elements are created starting from spheres, modified in the junction part toward polygonal modelling. The body that hosts the LED light source (which is not visible because the glass is opaline) with polygonal modelling starting from a half-sphere and the same, for the element that holds the luminaire on the ceiling; in this element some of the Polygons were removed in order to create the cuts for the wiring.

Cables and suspension wires are created starting from lines and curves. It is possible to create the element and then use a command to create a thickness (at a given diameter) or, it is possible to use the “Loft” tool.

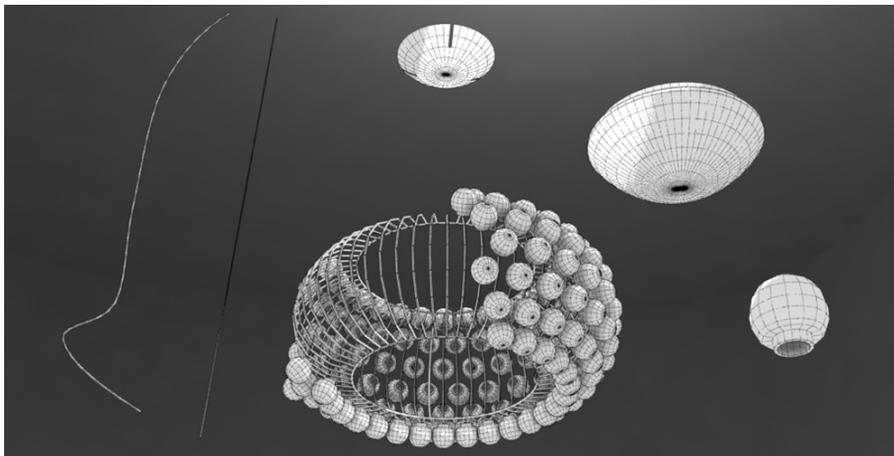


Fig. 7 – Basic geometric components for the 3D modelling of Caboche by Foscarini.

The materials for the Caboche line are an opaline blown glass for the luminous body, polymethylmethacrylate for the spheres and polycarbonate for the arches, stainless steel for the suspension cables and transparent electrical cable for the power supply.

The crucial element in this luminaire is the crown of spheres that refract the light coming from the luminous element placed in the center. In order to achieve this effect, the spheres must be considered as solid geometry so it is possible to take advantage of the index of refraction (around 1.49 for the PMMA) to achieve the refraction effect. The other materials should not be difficult.

The position of the photometric center, following the indications (figure 5, profile 10) of the European standard [6], is in the center of the suspended element (and not inside of the luminous body as logic may suggest). It is also important to pay attention to the orientation of the photometric web. In this case, for example, the emission of the luminaire is both direct and indirect. The designer must identify the right verse of the emission by looking at the polar diagrams of the luminaire on the catalogue or the manufacturer's website. In this case, the higher intensities are oriented downwards, so the photometric web must be oriented accordingly.



Fig. 8 – From left to right: picture of the luminaire, geometric model of the luminaire (red sign indicates the photometric center) and production render of the luminaire.

### 5.3. Aoy by Flos

The shape of this luminaire can be easily obtained from the cylinder primitive, paying attention to increase the amount of segments enough (if the luminaire is in the foreground an approximation to 32 segments may be a good choice).

The arch at the base is obtained by subtracting a shape (another cylinder) and refining the geometry with polygonal modelling, removing the unnecessary polygons and vertices created by the Boolean subtraction.

The opaline goblet inside of the cylinder can be obtained by extruding the upper part of the cylinder downward and then detaching it from the rest of the body.

The upper reflector is created by revolving a curve along the vertical axis (with a “Lathe” tool). Lathe can be used also to create the two elements that form the light bulb. The first three elements need to have depth, so the “Shell” command must be used. Also in this model, it is possible to use subdivisions in order to adapt the resolution of the polygonal mesh in relation to the position of the luminaire in the scene.

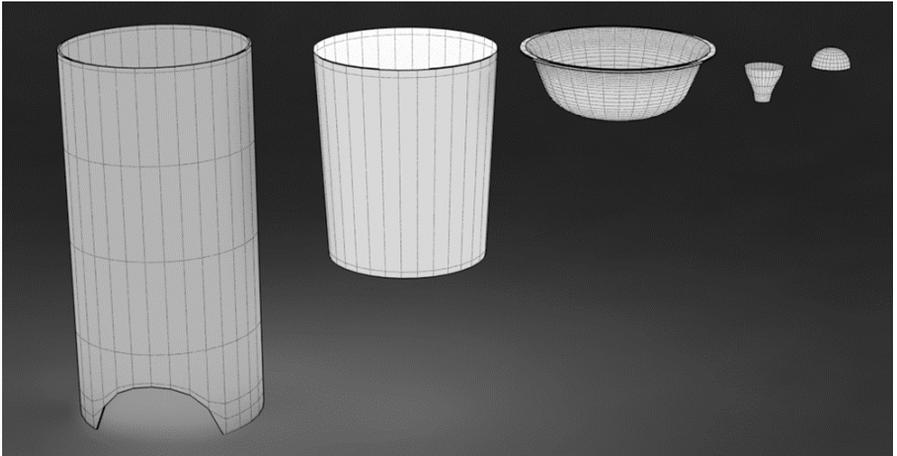


Fig. 9 – Basic geometric components for the 3D modelling of Aoy by Flos.

The external body is made of clear glass and the internal diffuser and reflector are made of white, opaline glass. The light source is a bulb, with the upper half with a chrome finish that serves as anti-glare system.

The position of the photometric web in this case is not in the center of the luminaire, but in correspondence of the light source. The European standard [6] states that for luminaires with transparent sides or without side members, the photometric center correspond to the lamp photometric center.

Another element to keep in consideration is that this fixture (in dark environments) creates a slight caustic effect at the base of the luminaire.

In order to achieve so, the software used must be able to calculate caustic, and the effect has to be set up properly.

The opaline diffuser and reflector may need a little improvement with a self-illuminated material and, to achieve the caustic effect (and for physical correctness), they also must be removed from the calculation of shadows together with the bulb.

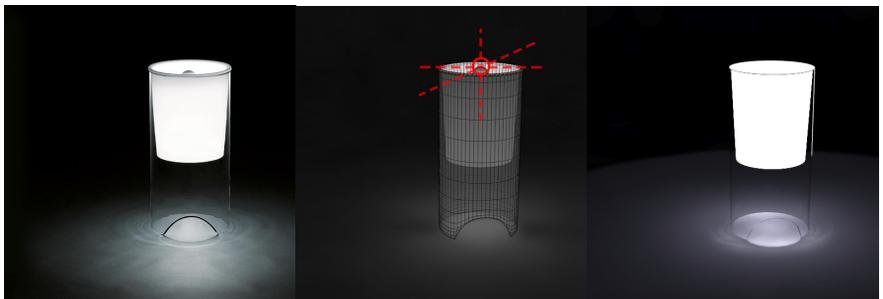


Fig. 10 – From left to right: picture of the luminaire, geometric model of the luminaire (red sign indicates the photometric center) and production render of the luminaire.

## 6. Conclusions

The techniques described can change in relation to the software used and the shape of the luminaires (that can span from very simple to incredibly complicated passing through an infinite number of variations). All the objects can be created in many ways, but the techniques described are efficient and allow the designer no to worry about the weight of the model (that can directly affect the time of calculation).

Synthesizing very quickly, the important steps are:

- The study of the luminaire (geometry, photometry and materials, directly on the catalogues or manufacturer website)
- What to represent (hidden components should not be modelled)
- Select the technique (the most efficient way to model all the visible parts)
- Scalability (trying to provide a method to change the resolution in relation to the importance of the luminaire in the scene)
- Correct position of the light sources (coupling the photometric data with the geometry, placing the photometric web in the correct spot)
- Creating the visual aspect of the object (materials and properties to set in order to respect the physics of the real world, and overcoming the limitations of the system geometry/photometry).

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