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**VERIFICATION OF ILLUMINANCE RENDERING FROM A
LIGHT SOURCE WITHIN 3DSTUDIO MAX 5.1**

(An approach to the Light Pollution assessment)

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The interest for the protection of the night sky from *Light pollution* is growing every day. Numerous organisms like CIE, IESNA, CONAMA, OPCC, IDA, etc. attempts to protect the quality of the sky from light pollution effects. Many countries are beginning to pass lighting ordinances, regulating the amount of light emitted, type of fixtures and even types of source. Most Local Planning Authorities taking decisions about global lighting policies live in cities following recommendations from the planning phases. Currently, new solutions are needed for handling and assessment of the light pollution problem. In this research, visualization with current 3D technology was the chose way for the reason that light pollution is considered as a visual problem.

The main objective of this research is to contribute to the development of a method, employing 3D software, which allows to verify the illuminance renderings from a single luminaire in absence of environment and atmospheric conditions. In this sense, the software 3D Studio Max 5.1 claims to use photometric basis on the method to verify the illuminance renderings. To achieve this main objective, the reference data are provided by Philips company such as the Isolux diagram and photometric data from the luminaire taken as example (203SGS armature and Son Plus 150w lamp). The verification of illuminance rendering in this research is achieved accomplishing geometric overlay between the reference data (Isolux diagram provided by Philips) and the iluminance rendering obtained in 3D Studio Max. In addition, a statistic study about the numerical results of illuminance rendering compared with the reference isolux diagram has been realized.

To achieve this goal, the research strategy followed is:

- 1) Investigating and studying the Light distribution representation.
- 2) Monitoring 3D software's tools, particularly *Advance lighting* and *Pseudocolor exposure* in 3D Studio Max 5.1.
- 3) Applying the method: defining spatial dimensions (coordinates system, scale and measurements) in 3D Studio Max to simulate the reference Isolux diagram.
- 4) Referencing of output illuminance renderings.
- 5) Verification of the illuminance rendering.
- 6) Statistics study about the numerical results.

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CHAPTER I. INTRODUCTION

1.1. CONTEXT

Nowadays, Light pollution is considered as a global problem which affects almost the entire human population. Cinzano *et al.* (2001) have defined light pollution as “*the alteration of the ambient light levels in the night environment produced by man-made light*”. Interest in Light pollution has been growing due to adverse effects it produces on the natural environment involving humans, flora and fauna, the night sky quality, public safety and health and a excessive waste of energy and budget (IDA's, 2002, Cinzano, et al., 2001).

There are several organisms like IESNA¹, IDA² and CIE³ that have passed or are beginning to pass lighting ordinances, regulating the amount of light emitted, type of fixtures and even types of light source in attempt to combat light pollution. The goals of outdoor lighting regulations should be to promote lighting design practices that are consistent with energy conservation, safety needs and the preservation of the natural night environment (IDA's, 2002). Then, following lighting regulations and planning options, Light pollution can be considered a manageable problem, and given certain lighting requirements an engineer could opt for several solutions that may result in different amounts of light pollution.

Once light pollution is produced, it can be measured. With the intention of quantifying the relationship between electric lighting and its effects, lighting professionals and astronomers have begun measuring light pollution. Scientific instruments and different methods have been developed to make these measurements (CIE, 1997, LRC, 2003). On the other hand, much researches are currently focused on estimating the lighting waste and saving of the most relevant urban surfaces such as roads, pedestrian ways, building facades, etc.; everything closely linked with several aspects of urban centre and nearby areas. This type of researches treats light pollution as a social and visual problem.

Despite the fact that light pollution can be measured, above all it is a visual phenomenon. As such it can be appreciated in the form of glare, light trespass or sky glow in urban areas, providing a huge damage to the aesthetics of the nighttime environment (Morgan, 2000).

Planners, engineers and governmental planning institutions could use computer simulations to perform light pollution assessment in the planning phase for a future lighting design. In an attempt to reduce energy consumption and improve night visual comfort, it could be simulated through *Visualization* as a means for studying the problem. Visualization would be particularly useful if it was based on a sound physical basis and if visualized scenarios could be compared against measurements of light intensities. Furthermore, the possibility of real-time interaction with the visualized model would enhance the usability of visualization tools.

Recent developments (power processors, graphics accelerators and standard hardware-implemented graphics libraries) have opened up new horizons for 3D visualization. Sophisticated devices or conventional equipment allow complete interaction with the model, simulating actions and observing reactions similar to those in the real world. The use of computer visualization is a powerful tool that has been applied for representation, assessment and research in many different

¹ IESNA: Illuminating Engineering Society of North America.

² IDA: International Dark Sky Association.

³ ICE: International Commission on Illumination.

disciplines. According to the previously mentioned, the most natural way to perform light pollution assessment is by 3D visualization, as one means for studying the problem.

Making use of the advanced technology that last version of 3D Studio Max 5.1 (Discreet) offer us, we will be able to verify the physical basis of renderings using the single luminaire data, concretely SON-PLUS 150w, provided by Philips Company. The luminaire data will be the reference data in the study because photometric measurements have been checked by photometric laboratories. Therefore, the software 3D Studio Max 5.1 will claims to do photometrically correct visualization analysis using calculation of light energy distribution based on physical theory. The package also supports the IES⁴ photometric format for importing the luminaire data supplied directly by lighting manufacturers.

1.2. PROBLEM DEFINITION

As a first step to approach us to a physical based lighting visualization about the light pollution assessment, in this study we would like to show how visualization of physical-based rendering of a single luminaire could contribute with specific support in a lighting design process.

The relevance in this research lies in the verification of 3D Studio Max 5.1 claims to be physically based. For this reason, the main objective will be to verify the renderings of illuminance from Philips luminaire which have taken as example. To achieve this objective 3D Studio Max 5.1 support lighting analysis tools and advanced lighting methods to represent the luminous intensity arriving to the surface, being to able to obtain a representative render (bitmap image) of the illuminance. As a result of the utilization of the device should be able to validate/verify the rendering of light from a single luminaire that will be done using physical-based software. Indeed, the luminaire of the study case has to be described using a photometric parameters set which will be introduced within the software.

The effectiveness of the software 3D Studio Max 5.1 will be checked by testing, comparing Isolux diagram (provided by a manufacture) against the illuminance render of the study luminaire. If verification was possible, we would have advanced a step in the difficult way to represent future environment impact assessment, as Light Pollution, with a physical basis.

If visualisations can to be useful for light regulation purposes they should be based on verifiable methods. 3D Studio Max 5.1 claims to use photometric basis on the method to verify the illuminance renderings. The problem is the software doesn't allow to measurement of illuminance at points of interest. Simply, the renderings obtained are bitmaps reproducing the illuminance value of a single luminaire falling on a horizontal plane and with avoid environment.

In this research is important to emphasize the complete process carried out is experimental. The methodology used treats to simulate within 3D Studio Max the real process employed at the photometric laboratories. Ours obtained results with the software are compared later with the photometric laboratories results.

⁴ IES: Illumination Engineering Society

1.3. OBJECTIVE

The main objective of the research is focused on contributing to the development of a method which allows to verify the 3D Max renderings of light from the Philips luminaire falling on a surface (illuminance). We should take into account that in the research haven't been studied the environment physical properties around the luminaire. In addition, the rendering of the isolux curve reproduced by 3D Studio Max from the Philips luminaire is exempted of atmospheric conditions. The environment and atmospheric conditions are considered to fall outside the scope of the present research.

To achieve the main objective we need to compare the output illuminance rendering obtained by 3D Studio Max of a single luminaire against the Isolux diagram (measured photometric data) provided by Philips. If the objective was aimed, the immediate conclusion will be that the software 3D Studio max 5.1 use physical basis to represent light distribution.

1.4. RESEARCH QUESTIONS

In order to achieve the objective of the research it is necessary to answer the following main questions:

1. How are photometric lights represented in *3D Studio Max*?
2. How can the 3D Studio Max renderings of illuminance be verified?
3. Do the 3D Studio Max 5.1 renderings of illuminance by a single lamp in void environmental conditions reproduce the Isolux curves of Philips luminaire (SGS203 armature and Son Plus 150w lamp) provided by Philips Company?
4. Which data/information are required to answer question 3, and can these data be provided by manufactures?

1.5. ORGANIZATION OF THE THESIS

This study has been divided into five sections. The nature of the introductory Chapter I and Chapter II is theoretical and general. Chapter I is vital for a sound understanding of the final results. This chapter introduces with the general aspects: the problematic and scope of the Light pollution concept, the significance to apply computer visualization as a means for studying Light pollution assessment and the importance to development a method which allows to verify the 3D Max renderings of light from a specific luminaire, being this last point the main objective of the study. Chapter II introduces some elements of photometric theory to get a clear understanding about the Light distribution from a light source through space. In addition, this part will explain the different light distribution representation and diagrams used to represent luminous emission of a luminaire focussing the main attention on the Isolux diagram. A complete description about the structure of IES file standard format will be detailed at the end of this chapter. Chapter III is devoted to how 3D Studio Max 5.1 represents Light distribution through space, from a photometric light source. Some concepts to introduce visualization and type of lighting with 3D Studio Max 5.1 are explained as well. Chapter IV is one of the most important in the study. It contains the methodology followed to develop the research. The chapter describes the procedure to be carried out to verify the 3D Studio Max rendering of light producing *Son Plus 150w* luminaire within software. The explanation of how Light distribution of the luminaire is transformed in two dimensions (bitmap image) in 3D Studio Max is described in this chapter. At the end, the design criteria of the real study case, its process and the results of the lighting

analysis are discussed. The chapter will finish by making the comparison between the output renderings obtained by 3D Max of the luminaire against the *Isolux curve* (measured photometric data) provided by manufactures. The last chapter includes the main achieved conclusions of the research and explain in detail all discussion points. The research is completed with the addition of three appendixes. Appendix I contains a glossary about lighting technology and concepts involved on the topic. Appendix II describe the IES file of Philips luminaire used at the study, and Appendix III shows the complete report of the same luminaire for further information.

CHAPTER II. PHOTOMETRY THEORY

This chapter introduces some elements of Photometric Light theory which were used to perform and measure luminous intensity. Therefore, this part is devoted to clarify the different light distribution representation and diagrams used to represent luminous emission of a luminaire by means of photometric units. Attention is focused on the isolux curve diagram which will be used in chapter 4 to verify the 3D Studio Max rendering of a single luminaire. Reference is made to Appendix I (glossary) where the used terms are further explained and more detail about lighting technology is provided.

2.1. INTRODUCTION

For a better understanding of this research, it is necessary to introduce the light propagation through space and to emphasize the importance of photometry in our study. The following explanations are brief theoretical introductions, aiming to clarify some of the concepts.

The vocabulary of quantified light energy comes from the field of radiometry. Photometric terms are simply radiometric terms weighted and scaled to a new set of units. Actually, radiometry was preceded by many years by *photometry*, which could be defined as “*the measurement of radiation evaluated in accordance with the visual impression*” (Keitz, 1971). The human visual system is only responsive to energy in a certain range of the electromagnetic spectrum. Only one part of the energy entering the eyes produces an impression of light that is the part of which the wavelengths lie between 0.4 and 0.7 μm . In this sense, the energy is evaluated in terms of the *sensation of light* produced in the eyes.

In this thesis, we have focused main attention on the light distribution and how luminous intensity in the visible range can be graphically represented.

2.2. LIGHT DISTRIBUTION FROM A LIGHT SOURCE.

In order to evaluate the luminous characteristics of a light sources it is necessary to know the radiated luminous flux in the various directions within the space around the source, that is, the distribution of the luminous intensity, termed the *Light distribution* of the source. It must also be possible to express light distribution numerically or graphically in order to use the data for later computations, interpolations from the given values or other calculation types (Keitz, 1971).

The general concept of a Luminaire is “*A complete physical structure for illumination that is composed of a lamp, a housing, and associated electrical and electronic support* (Glassner, 1995). Figure 1 show the luminaire which will be used in this research. Data on this luminary obtained from the Philips web site: <http://www.philips.com/>

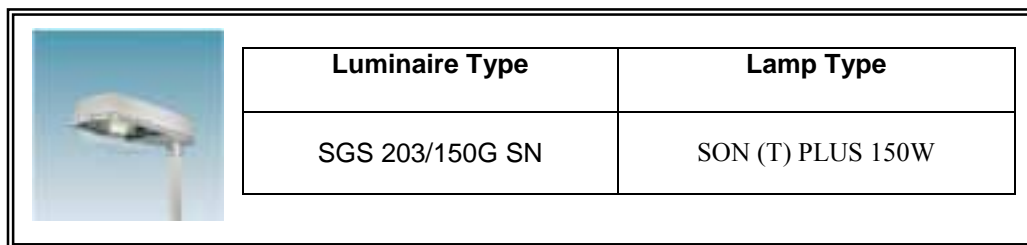


Fig. 1. Picture shows a particular luminaire with polyester canopy with gear provided by Philips Company.

A light source produces a distribution of the luminous intensity throughout a space. This luminous intensity distribution can be represented by a three-dimensional graph called *photometric solid*⁵, whose boundaries are represented by the whole of the luminous intensity values emitted in all directions (Ian Asdown, 1999).

Overall, photometric measurements indicate how a particular luminaire casts light. The photometric data describe a luminaire light distribution in terms of intensity (candela) and direction (degrees). Graphic representation of these measurements provides measurable information, indicating how the luminaire will be performed in the space. The most utilized graphical and tabular representations of light distribution are explained in the following section.

2.3. METHODS OF REPRESENTING LIGHT DISTRIBUTION

In this section we shall show how photometric solid may be represented in a plane. Different graphical representation of light distribution can be used. They differ in the coordinate system, projection system, reference point (where the luminaire is positioned) or photometric units that are used. Keitz (1971) describes the following graphical representations:

2.3.1. POLAR INTENSITY DIAGRAM.

This intensity diagram is the plane representation obtained doing a section through photometric solid passing by the optical centroid. The section gives as resulted a *Light distribution curve or Polar diagram* as figure 2b shows. Luminous intensity values are represented from a particular point known as the pole. But not all information regarding the photometric solid is given in the plane representation. Only, main verticals plane that make an angle 0, 45 and 90 degrees on the transversal plane (Figure 2) are commonly represented (Keitz, 1971).

It is common practice to normalize the graphics for a reference lamp of 1000 lumen. The normalization avoids having to make a graphic for each lamp, where the rated power (lumens) only varies. The unit for measuring luminous intensity is candela. Concentric circumferences represent the luminous intensity on the graph where the light source is the origin of them. The circumferences units are given in candela⁶ per 1000 lumen (cd/1000 lm) of the applied lamp. In order to find the real luminous intensity, the values on the curve can be multiplied by the real luminous flux of the lamp and divide by 1000 lm at which the lamp is rated (Luminotecnia, 2000, Keitz, 1971).

⁵ Solid photometric is the representation of a continuous function in tree-dimension from photometric distribution data (Ian Ashdown, 1999).

⁶ The directional strength of light or luminous intensity is measured in candelas. The candela has been defined by a source of radiation that radiates 1/683W per steradian at a frequency of $540 \cdot 10^{12}$ H.

2.4. ILLUMINANCE DIAGRAMS. THE PLANE ISOLUX DIAGRAM

The curves views in the previous sections (polar diagrams and isocandles) are obtained from characteristics of the luminous source, flow or luminous intensity, and give information about the shape and magnitude of the luminous emission. However, several diagram⁸ are possible to use to illustrate the *illuminance* (i.e. the amount of light falling on a surface) resulting from the use of particular lighting fittings. Specially, we shall now describe the *isolux diagram*, which will be used in this research.

An *Isolux diagram* consists of lines of equal illuminance, as show in Figure 4. These lines so obtained are called Isolux curves which are referenced to the iluminance, luminous flow received by a surface. The data are obtained experimentally or by means of calculated intensities. These graphics are very useful because they give information about the quantity of light received in each point of the work surface and they are especially utilized in public lighting (*Luminotecnia 2000*).

The isolux diagram is considered as a universal diagram, that is, it can be used for different mounting heights and lamps. Accordingly, the normalization to a fixed value is a great advantage because it avoids drawing a different graphic for each lamp of different luminous flux. In order to show the isolux curves as absolute values it is common practice to refer to **lamp of 1000 lm and 1 metre assembly height**. We have to take in account that in this type of diagrams, only refer to the horizontal illuminance.

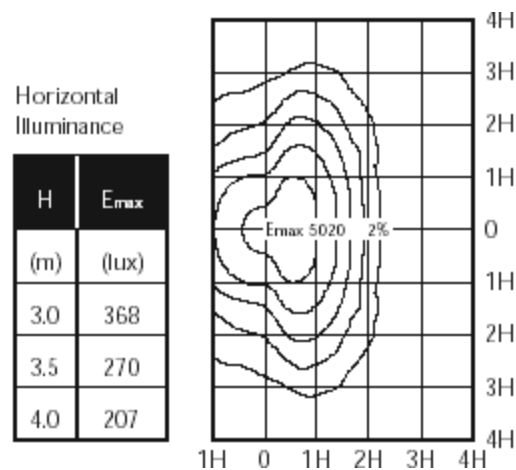


Fig. 4. Isolux diagram from Philips Company. It corresponds to the Son Plus 150w lamp and SGS203 armature. The left column of the table lists different mounting heights (H), whereas the right column lists the resulting maximum illuminance intensity at a horizontal surface below the luminaire (E_{max}). Note that the H coordinates in the horizontal plan refer to the mounting height. For example if the mounting height is 3 meters, shortest edge of the plane has a length of 15 meters. Each curve represented on the graph has the same amount of illuminance. The origin point with coordinates (0,0) represents the Maximum illuminance.

A Isolux diagram provide by Philips Company (Figure 4) don't follow the normalization previously mentioned, where the diagram is standardized for a lamp of 1000 lumen and 1 meter assembly height. The Isolux diagram is based on a coordinates system where the origin point has coordinates (0,0) and it is placed at the point where the illuminance value is Maximum. As the distance is increasing since the origin point, the illuminance value decreases according with the Inverse Square Law. From this point are drawn axis up with an H distance between them. H will

⁸ Other possible diagrams are: *Rectangular diagram*, *Solid of illumination* and *Polar Isolux diagram* (Keitz, 1971).

depends on chosen height and it will be linked to the maximum illuminance, that is, one unit H corresponding to 3, 3.5 or 4 meters. The distance between two consecutive axis and horizontal plane dimensions will depend on established valour H. Other particularity of the isolux diagram provide by Philips is that the curves don't represent illuminance values themselves, just percentages. In order to know the real illuminance value of a concrete point is necessary multiplier the percentage value on the curve by the Maximum Illuminance.

Importance of this kind of graph in this study is that we need to know the amount of luminous flux falling on a surface, that is, illuminance. In this sense, this graph will be our **reference data** and we will use it to compare it with the illuminance renderings obtained in 3D Studio Max.

2.5. IES FILES AS A TABULAR REPRESENTATION OF LIGHT DISTRIBUTION

Photometric Data includes measured product performance for lighting products, including luminous intensity, efficiency, and zonal luminous flux. Test reports are available from photometric laboratories and, electronic files are available from most lighting manufacturers. Several companies supplying luminaire data with a standard format file for (IES file) that the *Illumination Engineering Society of North America* (IESNA) designed for computational calculus. The contented information is obtained by testing for a specific luminaire and with special area test, where the angles measures are taken in a three-dimensional system (*Glassner, 1995, Line Associates, 2002*).

The standard consists of a file which contains a main block, and a photometric block. The main block describes the physical structure of the luminaire, including:

Table 1. Main block of IES file standard.

| Keyword | Purpose |
|------------------|--------------------------------------|
| <i>TEST</i> | Test report and laboratory |
| <i>MANUFAC</i> | Manufacturer of luminaire |
| <i>LUMCAT</i> | Luminaire catalog number |
| <i>LUMINAIRE</i> | Luminaire description |
| <i>LAMPCAT</i> | Lamp catalogue number |
| <i>LAMP</i> | Lamp description |
| <i>BALLAST</i> | The ballast used in the measurements |
| <i>MAINTCAT</i> | The maintenance category (integer) |

The photometric block describes how luminaire was measured and provides the actual data.

Table 2. Photometric block of IES file standard.

| Luminaire description | Physical set up of the luminaire |
|------------------------------|--|
| <i>NUMBER OF LAMPS</i> | This is the number of the lamps mounted in the luminaire. |
| <i>LUMENS PER LAMP</i> | This is the initial rated lumens for the lamp used in the test or -1 if the absolute photometry is used and the intensity values do not depend on the different ratings. |

| | |
|------------------------------------|--|
| CANDELA MULTIPLIER | The photometric data at the end of the file may be uniformly scaled by this value. Normally the multiplying factor is 1. |
| NUMBER OF VERTICAL ANGLES | This is the number of angles that were measured from pole to pole for this report. |
| NUMBER OF HORIZONTAL ANGLES | This is the number of angles that were measured around the equator for this report. |
| PHOTOMETRIC TYPE | This is the integer which of the three goniometric configurations was used to measure the data. |
| UNITS | Identifies the measurement system. A value of 1 are feet, a value of 2 are meter. |
| WIDTH | The width of the luminous opening. Normally 0. |
| LENGHT | The length of the luminous opening. Normally 0. |
| HEIGHT | The height of the luminous opening. Normally 0. |
| BALLAST FACTOR | This is the percentage by which the output of a lamp diminishes on a ballast. |
| BALLAST LAMP FACTOR | This factor gives the correction to turn the file data into the installation. |
| INPUT WATTS | This is the total watts applied to the luminaire for the test (including ballast) |
| VERTICALS ANGLES | This is the list of the verticals angles where measurements were taken, in degrees, in ascending order. If the distribution lies completely in the bottom hemisphere, the first ad the last angles must be 0° and 90° respectively. If the distribution lies completely in the top hemisphere, the first and last angles must be 90°and 180° respectively. Otherwise, they must be 0° and 180°, respectively. |
| HORIZONTAL ANGLES | This is the list of the horizontal angles where measurements were taken, in degrees, in ascending order. The last angle determines the degree of lateral symmetry displayed by the intensity distribution. If it is 0°, the distribution is axially symmetric. If it is 90°, the distribution is symmetric in each quadrant. If it is 180°, the distribution is symmetric about the vertical plane. If it is greater than 180° and less than or equal to 360°, the distribution exhibits no lateral symmetries. All other values are invalids. |
| INTENSITY | These are a simple long list of floating-point real numbers, separated by white space generating a matrix of values. Intensity is measured in candelas. |

In order to make us the clearest visual idea, the Figure 5 shows the three-dimensional representation of a photometric web such as IES file done the interpretation.

The luminous intensity distribution of a luminaire is measured at the nodes of a photometric web for a fixed set of horizontal and vertical angles. We start at the first vertical angle through each of the horizontal angles, and taking from the list the value in candelas for a node of the luminaire. Then we move to the next vertical angle and start the horizontal list another time and moving up the associated vertical plane. Finally, it generates a mesh formed by these values. This type of photometric web is generated by a goniophotometer⁹ and is the most used in architectural and roadways.

This tabular representation of a photometric web is interpreted by 3D Studio Max 5.1. The software can use IES files or other web files (CIE¹⁰, CIBSE¹¹, LTLI¹², EULUMDAT¹³, etc) to account for light distribution. In our particular case, the photometric web is compost on 37 vertical angles lain between 0 and 180 degrees and 27 horizontal angles lain between o and 180 degrees. It means the distribution is symmetric about the vertical plane.

⁹ A goniophotometer consists of a mechanical device to support and optionally position the light source and a photosensor, together with associated electrical and electronic equipment to acquire and process the photometric data.

¹⁰ CIE: Commission Internationale de l'Eclairage. (www.cie.org).

¹¹ CIBSE: Chartered Institute of Building Service Engineers, UK. (www.cibse.org).

¹² LTLI: The Danish Illuminating Laboratory developed in the 1970s the LTLI Luminaire Photometric File Format.

¹³ EULUMBAT: Photometric data file format developed by Axel Stockmar, Germany.

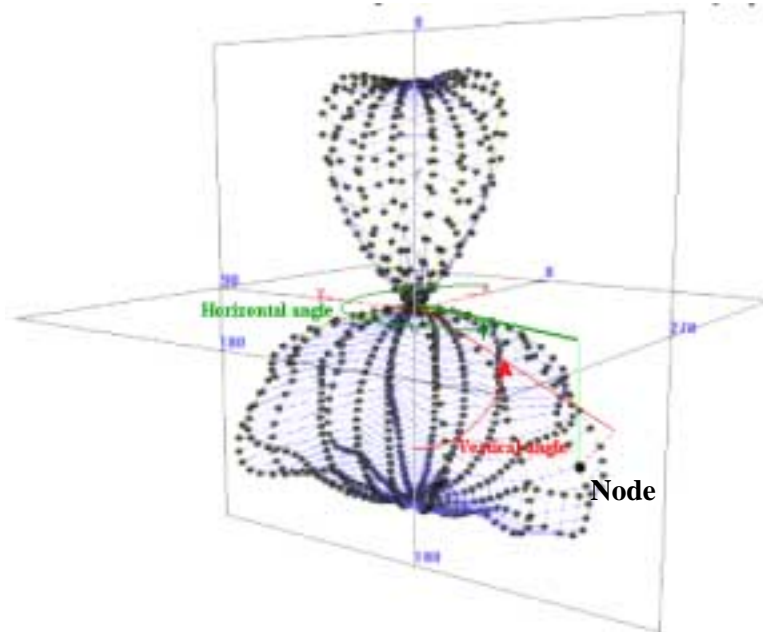


Fig. 5. Photometric web representation according IES file. Interpretation of the verticals and horizontal angles regarding an example node.

2.6. CONCLUSION

Luminous intensity distribution produced by a light source can be represented by a three-dimensional graph called *photometric solid*. This distribution of luminous intensity can be expressed numerically or graphically to be used for later computational calculus. The plane graphical representation of the photometric measurements provides measurable information, indicating how the luminaire will be performed through space. But, we have to keep in mind the important difference between luminous intensity and Luminous flux and how to represent graphically each one of them. Polar diagram and isocandela diagram give information about the shape and magnitude of the luminous emission in candelas. However, Isolux diagram is referenced to the Illuminance, luminous flow received on a surface, measurement in Luxes. As a common practice, all diagrams are normalized in order to avoid having to make a different graphic for each luminaire.

The IES file is a tabular representation of Light distribution of a luminaire where luminous intensity, efficiency, and zonal luminous flux are represented. The standard format file was designed by *Illumination Engineering Society of North America* (IESNA) by testing in photometric laboratories. The three-dimensional representation of Light distribution generates a mesh composed by nodes with a specific intensity value each one. These nodes are distributed according to verticals and horizontal angles (in degrees) where the measurements were taken.

CHAPTER III. LIGHTING PHOTOMETRIC USING 3D STUDIO MAX 5.1.

In this chapter we focus our attention to put into practice the overall theory about Light distribution from a light source. The following section tries to explain why is important visualization in this research and later, how 3D Studio Max transforms the real light distribution into a scene using the available light source, taking into account that the possibility to choose among different distribution capabilities only photometric light have it.

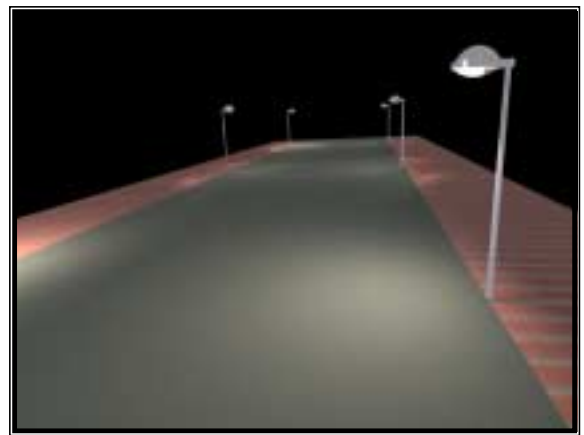
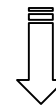
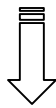
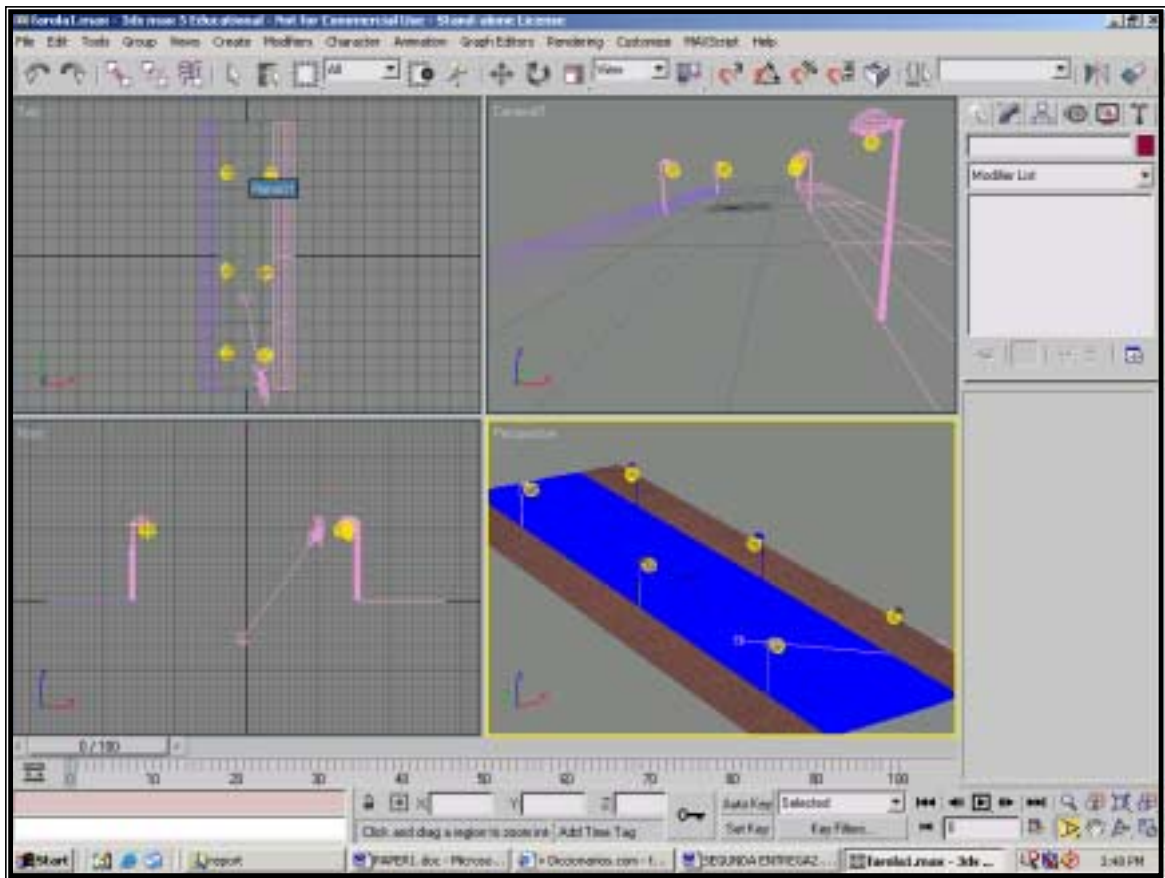
3.1. VISUALIZATION AND RENDERING WITH 3DSTUDIO MAX.

As it has been said in the introduction light pollution, is above all, a visual phenomenon caused by elevated outdoor lighting levels. Therefore, visualization of light provides an excellent means to analyse the problem. Besides, in this last version new lighting tools are available which allows the creation of photometric lighting and support lighting analysis tools to carry out the research. Below, a brief explanation of the visualization concept with this software is given.

3D Studio Max software allows to create three-dimensional objects with realistic appearance. The Software includes many tools by means of which is possible to create the object's structures in three dimensions and later to create a scene. So, everything that has been created in 3D Studio Max is located in a three-dimensional world in which is necessary has a variety of options for viewing this enormous space from details of the smallest object to the full extend of a scene (3D Studio Max Help, 2003).

Closely to the visualization, in order to get a final representation with all possible details, a number of calculations in relation to the surface, lighting and shadows are necessary to be executed. This process is called *rendering* and it is the result of taking a 3D geometric description and making a 2D image from a specific viewpoint. These images are only bitmaps can be stored in different formats like, bmp, jpeg, etc. (3D Studio Max Help, 2003).

With the purpose of giving as an example, the following picture shows a simple visualization of a road with a particular streetlamps (High-pressure sodium lamp). The final rendering (bitmap images) was made on the basis of an imported IES file describing the light distribution of the luminaires. We note that these renderings have been made without taking into account the environmental properties. Some of these properties are refraction, reflexion, transmission, colour properties, texture, opacity and so on, which affect light distribution in the scene. In addition, the objects that form the scene are exempted of whatever atmospheric conditions and effects.



(a)

(b)

Fig. 6 (top). The 3D viewer in 3D Studio Max through its four different windows. The first (upper left) shows a perspective from the top, the second shows a perspective from a camera placed in front of the viewer, the third shows a perspective from the front and the fourth is a general perspective.

Fig. 6(a) and **Fig. 6(b)**. Different renders with different perspectives of the previous design of a road.

3.2. PHOTOMETRIC LIGHT IN 3DSTUDIO MAX

Depending on the design type and the level of realism that would like to get, the software includes different types of light.

1) The first method is to create *standard lights*. They are point objects (light source) that simulate real world lights without using real physical bases. These can be the standard omni, spot, directional lights and Skylight. The parameters for standard lights are common to all types, being the most important intensity¹⁴, colour¹⁵ and attenuation¹⁶, used to define a specific lamp. Each one of them has the possibility to use the *Area light* to add lights that have geometry. For example, assigning this kind of light can simulate a fluorescent light box. The area light works with the standard Max rendering system and can be used with or without radiosity¹⁷ lighting (to be explained below).

2) The second option is the most valuable in this research, that is, the use of *Photometric light*. Photometric lights use photometric (*light energy*) values that enable more accurately define lights. They can accurately modeller the intensity, colour, and distribution of light, as they would be in the real world. Because photometric lights use real-world intensity values, they rely on accurate scaling in the scene; for instance, a photometric light with a 60W bulb's intensity cannot light a model of a city. Besides, the use photometric lights with radiosity will serve to obtain physically accurate lighting in renderings. In addition, the best advantage is can import specific photometric files available from lighting manufacturers. Photometric lights always attenuate using an *inverse square Law* (see glossary).

3.3. DISTRIBUTION CAPABILITIES OF LIGHT DISTRIBUTION

As it was said before, *3D Studio Max* provides physically based simulation of the propagation of light through an environment. In order to represent this propagation a new interface for defining and using real-world lights has also been introduced in the software. This advance permits the choice among three different *light distribution* options regarding to the type of photometric light. The photometric light sources support these distributions:

- *Photometric Isotropic distribution*: An Isotropic light distributes the light equally in all directions. A sphere centred on the origin is a representation of an isotropic distribution. All the points in the diagram are equidistant from the centre and therefore light is emitted equally in all directions.
- *Photometric Spotlight distribution*: A spotlight distribution casts a focused beam of light like a flashlight. At the light's *beam angle*, intensity has fallen to 50 per cent. At its *field angle*, intensity has fallen to zero.
- *Photometric Web distribution*: The photometric web is a three dimensional representation of the light distribution. It extends the diagram to three dimensions so that the dependencies of the

¹⁴ Intensity. Standard lights allow increase or decrease the light's Multiplier value to change a light's intensity.

¹⁵ Colour is used to specify a custom colour parameter for a lamp. There are three different colour selection models: Hue/Blackness/Whiteness, Red/Blue/Green and Hue/Saturation/Value.

¹⁶ Attenuation is the effect of light diminishing over distance being possible set attenuation values explicitly

¹⁷ Radiosity is rendering technology that realistically simulates the way in which light interacts in an environment. It is a physically accurate lighting simulation and requires that the scene be built to scale.

luminous intensity on both the vertical and horizontal angles can be examined simultaneously, so the system can compute the luminous intensity along an arbitrary direction by interpolation (see Figure 2). The centre of the photometric web represents the centre of the light source. The luminous intensity in any given direction is proportional to the distance between this web and the photometric centre, measured along a line leaving the centre in the specified direction (3D Studio Help, 2003). Web distribution in 3D Studio Max uses a photometric web definition¹⁸ to distribute the light. The directional light distribution information is stored in the IES files as explained in 2.5.

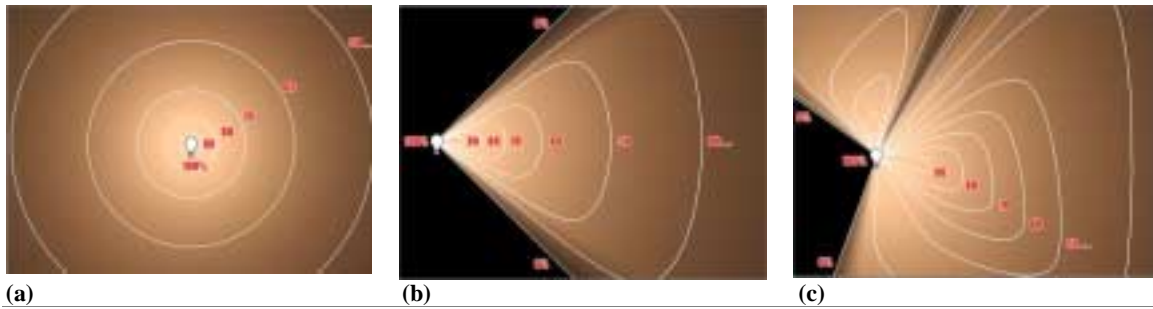


Fig. 7. (a) Isotropic Distribution. (b) Spotlight Distribution. (c) Web Distribution.

3.4. PSEUDOCOLOUR EXPOSURE

There are currently no possibilities to obtain numerical values of illuminance at user defined location in the scene. The only tool to analyse the amount of luminous flux from a light source falling on a given area with 3D Studio Max 5.1 is using Pseudocolour exposure. This control is actually a lighting analysis tool that provides a way of visualizing and evaluating the illuminance arrived to a surface. It maps illuminance values to pseudocolour through a valour scale whose range include from the highest to the lowest value of the amount of luminous flux arriving on a surface. The rendering represents a mapped of Illuminance using blue, cyan, green, yellow, orange, and red colours depend on luminous flux arrived to the surface. As a result of using pseudocolor exposure, we obtain bitmap images mapping illuminance values (3D Studio Max Help, 2003).

The handling and resulting renderings of illuminance from the Philips luminaire using Pseudocolour will be developed in section 4.1.5.

3.5. LIGHTING ALGORITHMS

Physically based light simulations contain global illumination algorithms¹⁹, which describe the distribution of light in a scene. Light leaving a surface originates from direct emission and from the reflections or transmissions within the environment. Correspondingly, light arriving a surface comes either directly from a light source or from reflections and transmissions. Currently, advanced rendering techniques that take into account reflective properties of materials, light

¹⁸ The photometric data produced by goniophotometers is presented as the luminous intensity of a point source at the photometric centre (nominally the centre of rotation) of the lamp or luminaire for various vertical and horizontal directions. The spherical coordinate system used to describe these directions is referred to as the photometric web (Ian Ashdown, 2001).

¹⁹ This algorithms take into account the distribution of Light in the entire scene when deriving the colour for any one surface point or image pixel (Glassner, 1995)

sources, illuminations, shadows and transparency are available. In 3D Studio Max 5.1 global illumination can be modelled using two algorithms, one based on *Radiosity* and the other based on *Ray tracing* to create lighting simulations.

➤ Radiosity simulates the diffuse²⁰ propagation of light starting at the light source. The main idea of the method is to store illumination values on the surfaces of the objects, as the light is propagated starting at the light sources. The process consists of a subdivision of the surface into smaller elements (*patches*) and the result is called meshing. At all patches of each surface it is assumed that the reflected, incident and emitted radiance are constant in all directions. The radiosity algorithm establishes a set of linear equations that relates the fraction of energy leaving one patch to the energy arriving at another, based on the geometry between the two patches. The result of the radiosity process is to know how much light is being reradiated by each surface (Glassner, 1995).

➤ Ray tracing assumes that objects are illuminated only by light coming directly from a light source, or via some intermediate bounces off of perfectly specular²¹ surface. The ray-tracing algorithm is very versatile because of the large range of lighting effects it can model. It can accurately account for the global illumination characteristics of direct illumination, shadows, specular reflections (for example, mirrors), and refraction through transparent materials. A significant disadvantage of ray tracing is that it does not account for one very important characteristic of global illumination, diffuse interreflections. With ray tracing, only the light arriving directly from the light sources themselves is accurately accounted (Autodesk, 2001)

3.6. CONCLUSION

3D Studio Max software allows to create three-dimensional objects, its visualization and its corresponding rendering (bitmap images) by means of sophisticated tools. As a physical based lighting simulation research, the purpose is focussed on represent photometric lights and their propagation through space (Light distribution) using 3D Studio Max 5.1. In this way, three different kinds of light distribution are possible to choose in the software: Isotropic Distribution, Spotlight distribution and Web distribution. Web distribution is the most important in the study being the corresponding to the Philips luminaire. The directional light distribution information is stored in the IES files relying on specific verticals and horizontal angles. The whole of those angles will generate the photometric web (three dimensional figure).

The pseudocolour exposure tool is the lighting analysis used in order to visualize and evaluate the lighting levels (illuminance) arriving to a surface. The renderings (bitmap images) obtained with this lighting tool maps the illuminance values account. This illuminance values are represented by means of a valour scale whose range lie the lower and higher illuminance valour. Illuminance values at each point of the surface are represented with different colour depending on the illuminance valour in this point.

In 3D Studio Max provides for two different lighting algorithms: Radiosity and Raytracing. Both of them are used in global illumination to represent the light distribution from a light source. Radiosity algorithms have to be used to achieve physical based simulations, as it represents light distribution in more realistic way.

²⁰ The surface gives off the same amount of energy per unit area in each direction from every point.

²¹ Specular reflections propagate light without scattering, as from the surface of a perfectly smooth mirror.

CHAPTER IV. STUDY CASE OF A PHOTOMETRIC LIGHT

This chapter describes the practical process carried out to verify of the 3D Studio Max rendering representing the illuminance of luminaire (composed by lamp and armature). We needed to find a technique that transform photometric distribution in three dimensions into a two dimensions plane showing Illuminance values that can be compared with the reference Isolux diagram. At the end, the design criteria of real study case, its process and the results of the lighting analysis are discussed.

4.1. METHODOLOGY

4.1.1. FLOWCHART.

In the next picture is represented each one of the stage and requirements necessary to verify the Philips luminaire rendering using the software 3D Studio Max 5.1. Afterwards, the explanation of the followed steps is described.

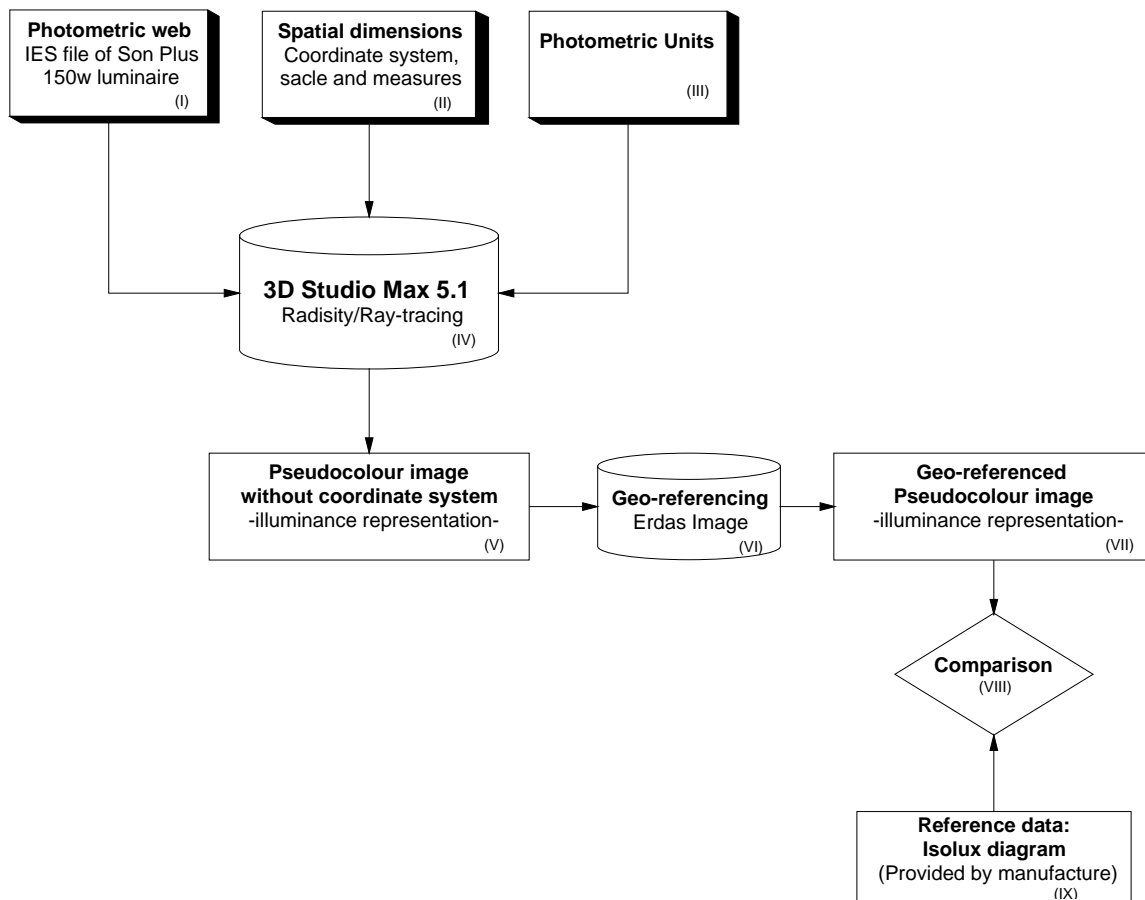


Fig. 8. The general scheme of the workflow. Interrelation among the theoretical concept (boxes: I, II and III), the implementation with 3D Studio Max 5.1 (boxes: IV and V) and the later comparison process with the original Isolux diagram supplied by manufacture.

- I. *Photometric Web*. The photometric web is a three dimensional representation of the light distribution from a light source where the luminous intensity depends on the direction for a predetermined set of vertical and horizontal angles (see Figure 2). The directional light distribution information is stored in the IES files with a specific tabular structure (see 2.5).
- II. *Spatial dimensions: Coordinates system, scale and measure*. We need a horizontal plane having the same dimensions as the Isolux curve diagram provided by Philips (Figure 5). In this sense, a specific coordinates system, scale and measure in 3D Studio Max will be build as section 4.1.4 explains.
- III. *Photometric units*. This section introduces the quantities used to characterize photometric measurements. We have to paid attention to three of them: Luminous intensity, luminous flux and Illuminance. They are the three more important in this thesis for the following reason. Luminous intensity is used to describe the directional distribution of a light source, that is, to specify how the luminous intensity of a light source varies as a function of the outgoing direction. The candela (cd) is the unit of luminous intensity. Luminous flux is the quantity of light energy per unit time arriving, leaving, or going through a surface. The lumen (lm) is the unit of luminous flux. Illuminance indicates the amount of luminous flux from a light source falling on a given area, divided by the area of the surface. It is measured in either *footcandles* (lumens per square foot, AS units) or *lux* (lumens per square meter, SI units). Illuminance decreases with the square of the distance from the light source (*inverse square law*).
- IV. 3D Studio Max 5.1 includes two lighting algorithms to create lighting simulations: *Radiosity* and *Raytracing*. Radiosity is an algorithm that calculates the light intensity of all surfaces in the scene. This frequently applies to the development of scientific visualization and virtual reality tools. The radiosity calculates the reflectance, transmittance, or amount of colour bounce (saturation) of any material. The radiosity application provides physically based results on final renderings. The use of photometric lights and a radiosity solution, ambient light is accurately calculated. For this reason, combination between photometric lighting and radiosity was the chose option. Ray Tracer is lighting engine provides multiple-bounce path tracing but is less accurate than the Radiosity. Yet, it is more interested in the appearance of a scene rather than physical accuracy.
- V. *Pseudocolour Image without coordinates system (Illuminance representation)*. The reproduction of the isolux diagram provided by Philips was carried out projecting the light (luminous flux) from the Philips luminaire to a surface (horizontal plane). In this purpose, to position the horizontal plane in 3D studio Max, we need to use a specific coordinates system, scale and measure (see 4.1.4) representing the reference isolux diagram. The finality of this simulation is to obtain the rendering of illuminance of the luminaire with the Pseudocolour Control²². The main problem when we obtained the pseudocolour rendering was that these renderings loose the coordinates system, they only kept the dimensions and size of the horizontal plane.

²² 3D Studio Max tool representing the amount of the luminous flux arriving to the surface. It will be explained next section.

- VI. *Geo-referencing*. The geo-referencing process was accomplished in Erdas Image software. It was necessary in order to position the pseudocolour rendering obtained in 3D Studio Max in the same coordinates system as the reference Isolux diagram provided by Philips. This coordinates system will be explained in section 4.1.4.
- VII. *Geo-referenced Pseudocolour Image (Illuminance representation)*. Once the geo-referencing process was finalised, the pseudocolour image is positioned in the same coordinates system as the reference Isolux diagram (Figure 9).
- VIII. *Comparison*. This is the stage where the verification of illuminance renderings could be accomplished. The verification was done in two different ways. The first was making a geometric overlay between the geo-referenced pseudocolour image with the reference Isolux diagram (see Figure 18). The second way was doing a statistics study comparing the illuminance numerical data of an area of interest. This area of interest will be the illuminance curves where we know the exact value, that is, the curves represented with 50%, 20%, 10%, 5% and 2% values.
- IX. *Isolux diagram*. This is only accurate reference data. The diagram represents graphically the luminous flux arriving to the surface, through curves with the same amount illuminance. This diagram corresponds to the Philips luminaire.

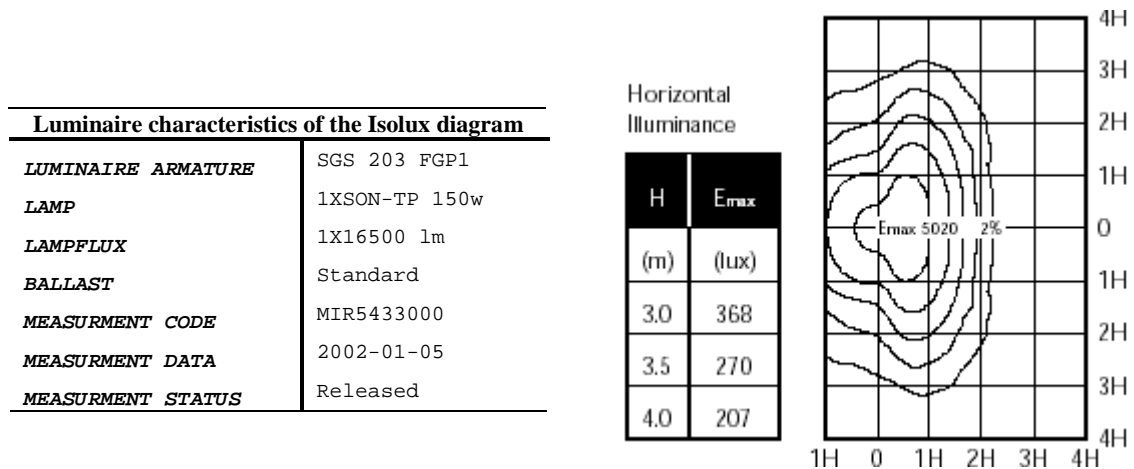


Fig. 9. The Isolux diagram for the luminaire and its technical characteristics.

4.1.2. INPUT DATA.

➤ **Light source.** The photometric data of the luminaire (lamp and armature) was provided by Philips Company in a complete report (see Appendix III). This light source is a High-pressure sodium lamp (see glossary). This type of light source are the most commonly used for street lightings for its efficiency (from 80 to 150 lm/w), long lamp life (at the least 24000 hours), excellent lumen depreciation and maintain their light output well for long periods of time. High-pressure sodium lamps are used where efficiency is the most important factor and colour is not as important. The most relevant characteristics of SON PLUS 150w lamp in the research are:

| Lamp reference | Watt | Lamp armature | Lumen ²³ |
|----------------|------|---------------|---------------------|
| 150 T PLUS SON | 150 | 203 SGS PH | 16500 |

➤ **IES file.** In the IES files are described all characteristics about the luminaire. The photometric data of Philips luminaire is stored in an ASCII file. The file that we used in this research is called **SGS203_150TFGP[1].11xSON-TP150W.ies** (for a complete description of the IES file of luminaire, see Appendix I).

4.1.3. SELECTION OF THE PARAMETERS

The first step to represent a photometric light in 3D Studio Max is to select on the Create Panel the Lights option. Choose **Photometric** from the drop-down list because the default is Standard light. After that it is possible to choose among different photometric light types. In our particular case, we used the option Free Point Light because the luminaire is considered as a point light. Then, the light was inserted²⁴ in an indeterminate position on the view port clicking over the screen and after, we used the Move transform to position it at the exactly coordinates (see 4.1.4).

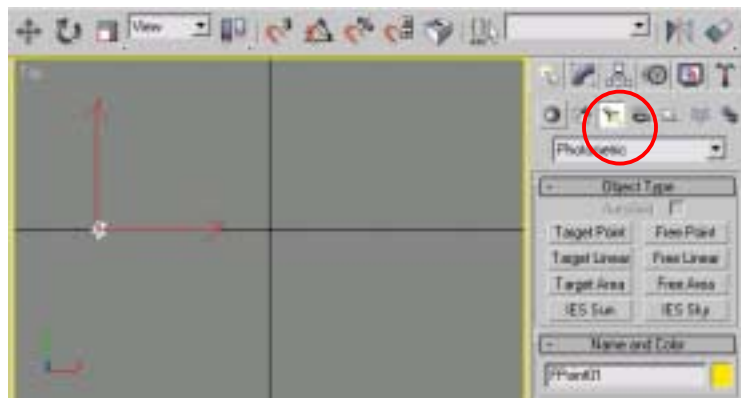


Fig.10. Create panel window where we can choose photometric lights type. The rectangular window with the yellow edge represents a top view where you can position the light.

²³ Lumen: The basic unit of measurement for amount of light produced by a lamp once it is started . The SON PLUS 150w lamp put out an intensity luminous powerful of 16.500 lumens.

²⁴ 3D Studio Max 5.1 uses a three dimensional system to position objects.

After positioning the photometric light, its parameters were modified. The following window of 3D Studio Max is the clearest way to explain *the photometric lights parameters*. In this part of the chapter are described each one of the parameters we had to change to adapt them to the specific photometric light (Philips luminaire).

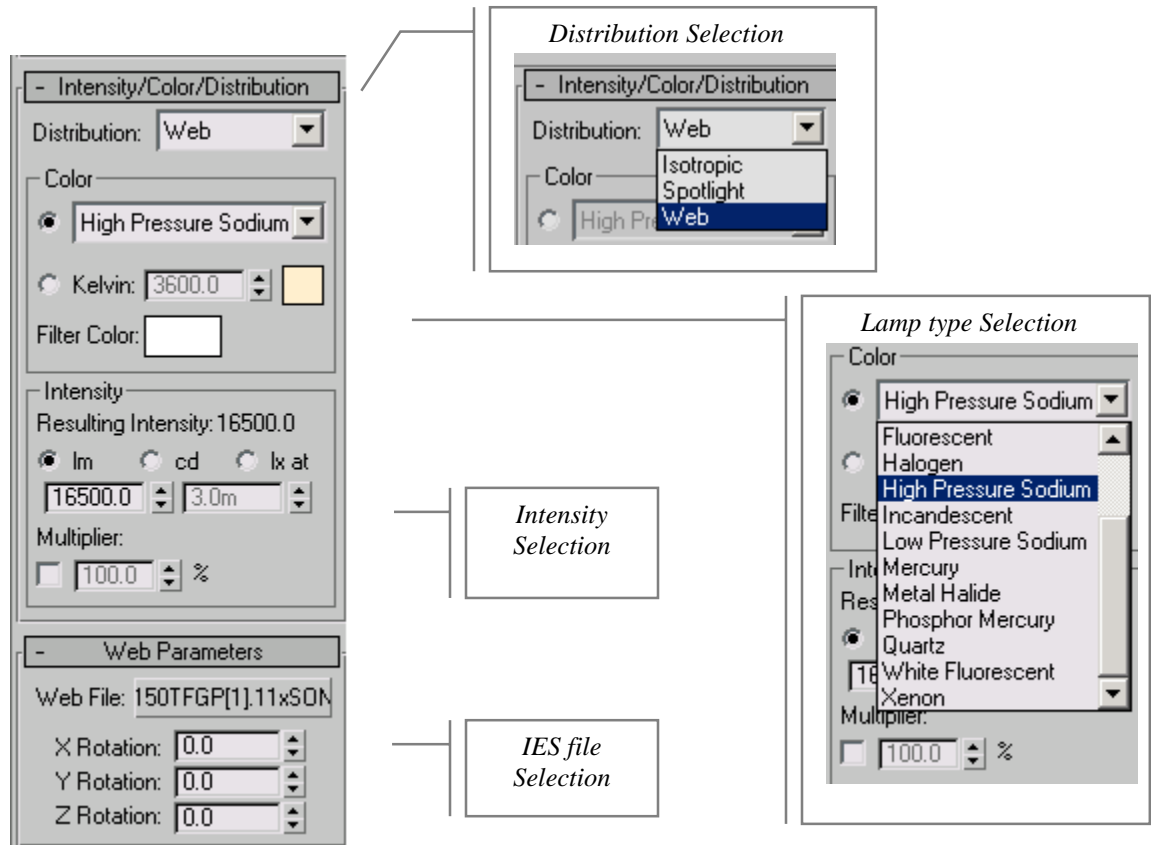


Fig. 11. Main window in 3D Studio Max for the parameters of a photometric light selection

1) Firstly, we chose the kind of distribution necessary to use into the work. For this, is necessary know which are the light distribution of the lamp that we will use in the study. In this case, we used Philips luminaire which has a **web distribution** (see chapter 2, *types of distribution*). After selecting the appopiate option the corresponding IES file could be loaded.

2) In the Web Parameters rollout chose the IES file that we wanted to use. Then, we selected the button labelled *web file* and navigated to the location of the file we wanted to **import**. The IES file corresponding to the Philips luminaire is called SGS203_150TFGP[1].11xSON-TP150W.ies. In this moment, software start to work with the parameters that there are inside of the IES file, like the vertical and horizontal angles (see Chapter II, section 2.5) and the luminous flux of the lamp, that is, 16500 lumens.

In the same rollout, the possibility of change the orientation of the photometric light imported, rotating X, Y and Z coordinates of the photometric light, is also possible. We used 0 degrees for x, y and z coordinates, respecting the default orientation that the IES file has. The luminaire orientation is fixed in photometric laboratories at a concrete position, so the corresponding isolux diagram and IES file is done with this specific position.

3) We specified the type of lamp that we had to use depending on IES file imported. In this rollout, light color based on a common lamp specification to approximate the spectral characteristics of the light is defined. Concretely, we applied the **High Pressure Sodium** (see glossary) because the Philips luminarie imported correspond to this type.

4) One of the most important factors of this research is the **intensity**²⁵ of photometric lights. In this section is possible to choose the physically based quantities among lumen, candela or lux. The resulting intensity of the light source has to be selected using one of the options. To represent luminous flux²⁶ produced by Philips luminaire we chose LM (lumen) option, where the measure is 16500 lumens.

In this section have been explained the representation of Son PLUS 150w lamp. We have to keep in mind that in order to carry out the process with a physical base, photometric information about the luminaire had to collected. After that, the parameters such as intensity, colour and distribution data provided by IES file permitted to define the lamp exactly with its photometric properties.

4.1.4. COORDENATES SYSTEM, SCALE AND MEASURES. SPATIAL DIMENSIONS.

Once the parameters of Philips luminaire were known, the reproduction of isolux diagram in 3D studio Max could be carried out. In order to obtain the rendering of light of the luminaire with the Pseudocolour Control²⁷, it was necessary to simulate our scene in three dimensions. It consists of:

- The emitted light from Philips luminaire, once imported in 3D Studio Max.
- A plane with specific dimensions where the light produced by lamp will be projected.

3D Max had exactly to simulate the isolux diagram supplied by Philips (see Figure 10). This operation was only a translation of the coordinates system that, at the beginning is placed at the Maximum Illuminance point regarding the original Isolux diagram. Making in account measurements and data of this diagram we could build the “3D scene” in the following way:

1) We built a horizontal plane where the emitted light from the luminaire falling above it. This is the way in 3D Studio Max to measure the illuminance. Light has to be projected to a surface. So according with the isolux diagram provided by Philips where, the horizontal plane was made with the following dimensions:

²⁵ Luminous intensity: The luminous intensity (candelas) is the strength (intensity) produced in a specific direction.

²⁶ Luminous flux: The measure of the total light producing power of the light source. Unit: Lumen.

²⁷ 3D Studio Max tool in order to represent the amount of the luminous flux arriving to the surface. It will be explained next section.

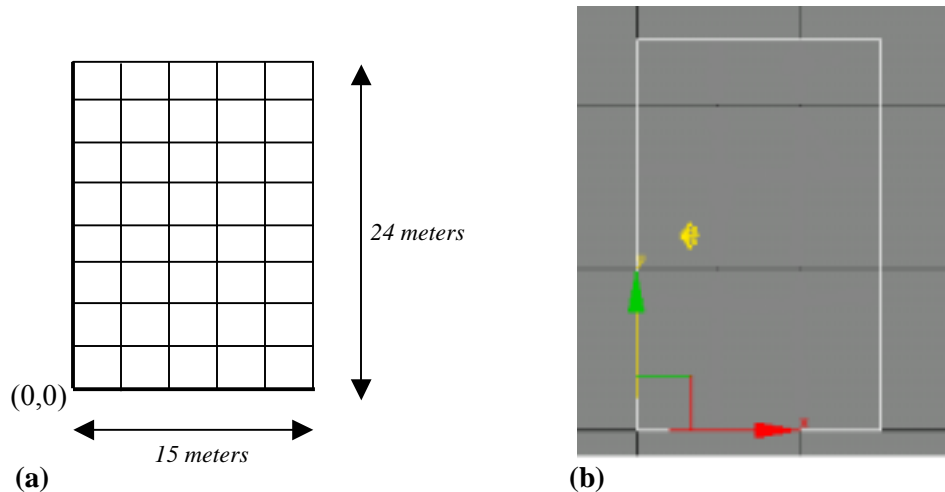


Fig. 12. (a) Isolux diagram reproduction as a dimensionable plane. (b) 3D Max window from an upper view. It represents the horizontal plane with the exact coordinates system. The yellow spot depicts the light source.

If we paid attention to the figure 10, one H unit correspond to 3 meters. Therefore, the plane has the following established dimensions:

- Y-axis: 24 meters (8 H units length, 3 meters each).
- X-axis: 15 meters (5 H units width, 3 meters each).
- Z-axis: 0 meters (we will suppose the plane high adimensional).

The coordinates system origin (0,0) is positioned on the left low corner.

2) Photometric light was positioned to a distance (high) from the plane of 3 meters. The main reason was because the Illuminance decreases with the square of the distance from the light source, that is, *inverse square law* (see glossary). From a transversal view for a H= 3 meters of high whose maximum illuminance (E_{max}) is 368 luxes, the figure was the following:

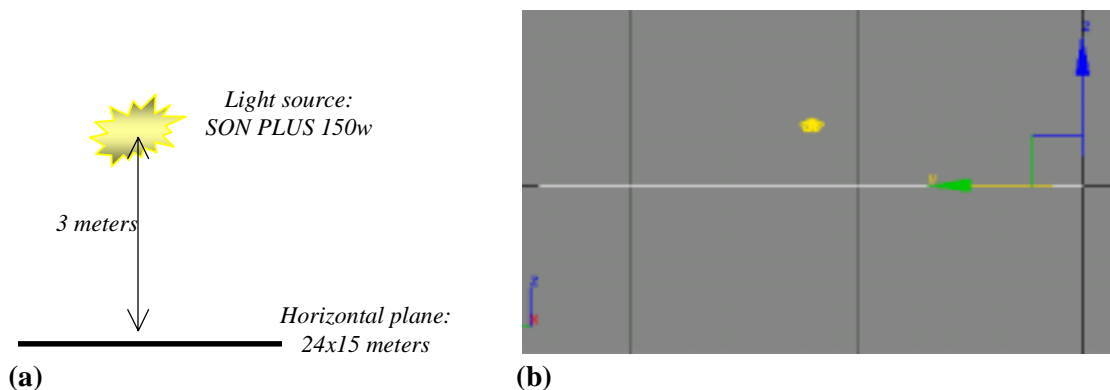


Fig.13. (a) Light source representation from a transversal view with real coordinates. (b) 3D max window from left view (transversal). The distance between light source and the horizontal plane are 3 meters.

Light source regarding the coordinates system explained had coordinates (3,12,3).

3) Once the objects were positioned at their respective coordinates and dimensions in 3D Studio Max, we could make a pseudocolor rendering that is to be compared against the Isolux diagram provided by Philips. The handling of this tool will be explained with all details next section.

4.1.5. PHOTOMETRIC LIGHT ANALYSIS.

4.1.5.1 PSEUDO COLOUR EXPOSURE

Subsequently, the follow 3D Max window shows the basically settings used to make the illuminance rendering.

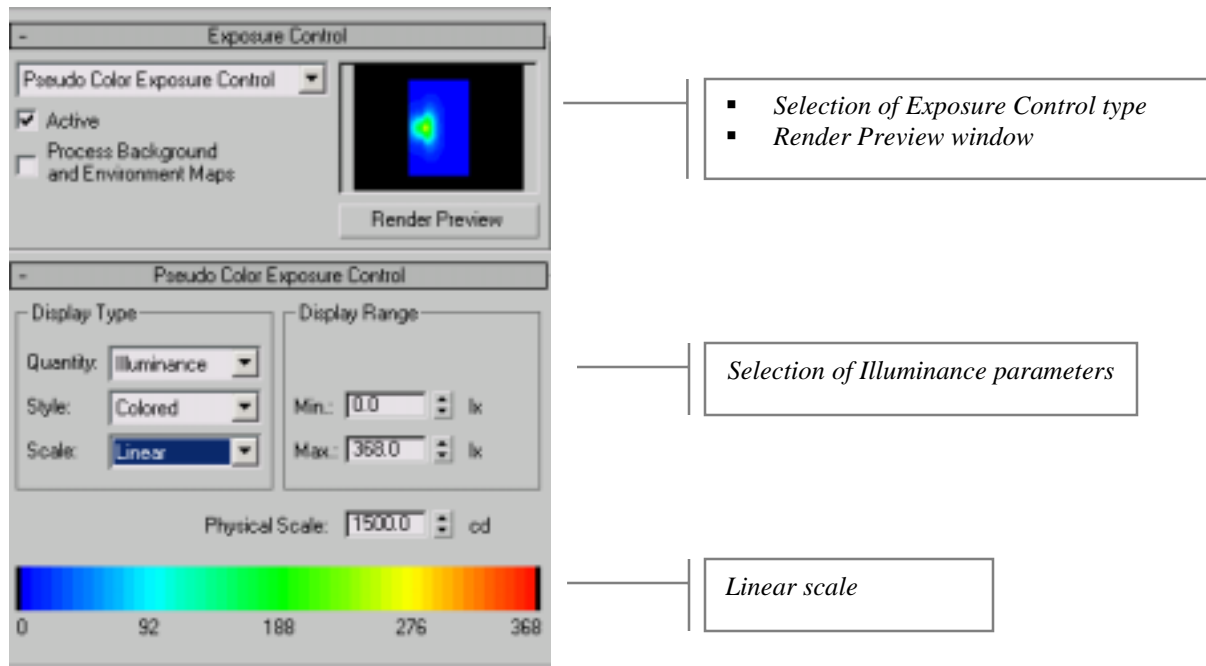


Fig. 14. Pseudocolour exposure window. It is divided in three sections. First section shows a Render preview of the illuminance provided by SON PLUS 150w lamp. Second section, shows each parameter that we have to introduce to represent the rendering; and third section shows the values scale lied between maximum and minimum values of illuminance.

The process to obtain the illuminance rendering produced by luminous flux from the Philips luminaire with Pseudocolour Exposure control was accomplished through next stage:

1. In the first group, *Display Type*, it was required the use of *Illuminance* in order to know the amount of luminous intensity arriving to the surface.

In addition, we decided to use *Grey Style* (grey tones that range from white to black) against collared scale (a spectrum values). This decision was chose because the collared style is based on RGB colour scale, and it is compost for 3 bands such as red band, green band and blue band. So it is easier to work with an only band with grey levels scale because these grey levels have to be converted into percentage or illuminance values. Grey scale will facilitate the later comparison between the diagrams.

Finally, the selection of linear scale determinate the type of scaling used to display the data in the pseudocolour rendering. Linear scale uses a lineal mapping of data values to represent de illuminance values and we can know the intermediate illuminance values from of the linear scale. Completely opposite it happens with the *Logarithmic scale* used by 3D Studio Max. We are unaware of the logarithmic function used on the 3D Studio Max for its mathematics calculus when the software shows the logarithmic scale in the pseudocolour exposure control windows to represent the illuminance values.



Fig.

2. In the second group, *Display Range*,

To restrict the range of data used by the pseudocolour plot to generate its output was necessary to use this option. Once selected this button, the *Min* and *Max* text fields will become active, and we established the range to use. In this sense, the concrete values that we had to introduce to reproduce the isolux curve provided by Philips are the values of the Figure 14. Then, we focussed our attention in the Maximum illuminance (E_{max}) for a distance between the lamp and the light receiver plane of 3 meters. The Maximum value in this situation is 368 Luxes and it represented the last value in the lineal scale. The Minimum value was established in 0 and it corresponded to the first value in the lineal scale.

Finally, once the maximum and minimum (0-368) values are established, the illuminance rendering could be drawn. The Lineal scale is composed by four equidistant intervals which lie 0-92, 92-188, 188-276 and 276-368.

The logarithmic scale comprises the same range, the minimum valour is 0 and the maximum valour is 368. The scale are divided on four intervals which lie 0-3, 3-19, 19-83 and 83-368. We don't know the logarithmic scale used in the software to represent the scale and its corresponding intermediate values.

3.Physical Scale: Sets a physical scale for exposure control to use with lights that are not physically based. The result is an adjustment of the rendering that approximates the eye's response to the scene.

Summarizing, in this section have been able to see as the rendering produced by 3D Studio Max of the single lamp in our study has reproduced the isolux curve of the luminaire provided by Philips Company. It has been possible using Pseudocolour exposure tool and the isolux curve data supplied by Philips as well.

4.2. THE ILLUMINANCE RENDERINGS FROM PHILIPS LUMINAIRE.

Once the Pseudocolour Exposure tool was applied on the horizontal plane (see 4.1.4 and 4.1.5) the illuminance rendering resulting is represented on next figures.

The illuminance renderings produced by 3D Studio Max are simple bitmap images. For this reason, once reproduced the renderings they lose the coordinate system previously established, keeping only the dimensions. This is a considerable problem because we cannot to measure the amount of light intensity arriving to the surface (horizontal plane) at specific points.

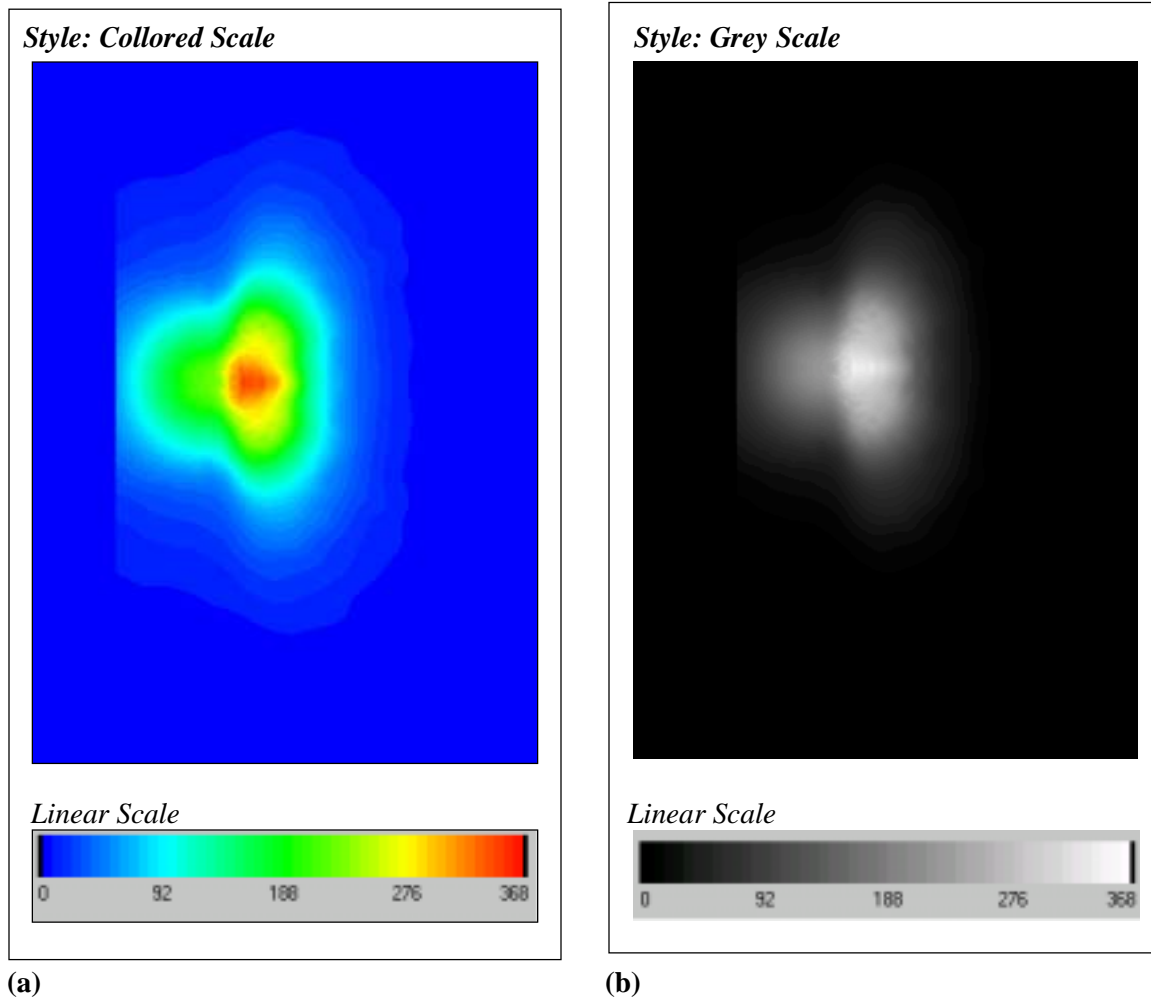


Fig. 16. (a) Figure shows the illuminance rendering using the colored style and linear scale. (b) Figure shows illuminance rendering using the grey style and linear scale. Both of them as result to apply Pseudocolour tool on the horizontal plane.

As we explained at section 4.1.4, in order to obtain the illuminance rendering we described a coordinates system corresponding to that of the reference Isolux diagram (see Figure 12 and Figure 13). So the horizontal plane where the light intensity is projected has the same dimensions that the reference isolux diagram. As on the Figure 16 can be appreciated the horizontal plane boundaries aren't represented. The reason is because in this rendering is considered in colour blue (0 valour) where the luminous flux doesn't arrive. Therefore, making a rendering from the top view window in 3D Studio Max (Figure 17) the boundaries are perfectly visible. The top view window in 3D Studio max is one of the four perspective views that can be chosen (see Figure 6

top) in the complete screen making a design. This view in general is a perpendicular upper view and, in our case, containing the horizontal plane created in 4.1.4 section (same dimensions and size) that the isolux diagram of Philips. These horizontal plane boundaries (concretely the four corner) served to reference the illuminance rendering of the Figure 16b.

We have to mention that the illuminance rendering that we used at the rest of the methodology was the **Style Grey scale** (Figure 16b)

4.2.1. ILLUMINANCE RENDERINGS GEO-REFERENCING.

To accomplish the comparison between the reference isolux and the output illuminance rendering obtained in 3D Studio from Philips luminaire, we need that both are placed in the same coordinates system. But the main problem is that the output illuminance rendering (the bitmap image) loses the coordinates system that we established in section 4.1.4, only keeping the dimensions. So we needed to reference the illuminance bitmap image for the later geometrical overlay.

The geo-referencing process of the illuminance rendering produced by 3D Studio Max was accomplished by ERDAS IMAGE software. The referencing process of an image is assigning coordinates to image data. This process includes the operation of geometric transformation between two images called rectification (Schok *et al.*, 2001). To carry out the referencing we did the following steps:

1) To reference the Style Grey illuminance rendering (Figure 16b) is necessary to know the coordinates of a minimum number of points of the reference image. These points (called in Erdas Imagine “Ground Control Points”) will be the four corners of the horizontal plane because they are clearly identifiable. So we need to resort to the top view window rendering showing next:

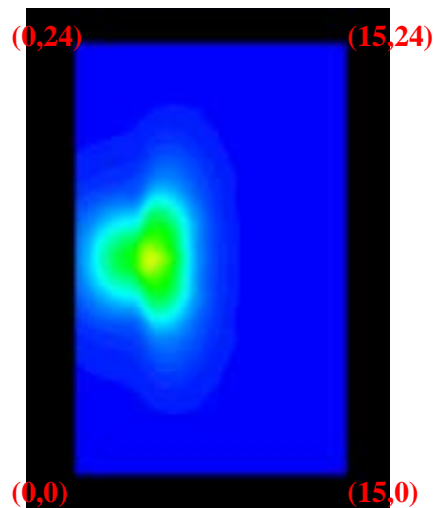


Fig. 17. Figure shows the rendering of the top view window in 3D Studio Max. The dimensions of the horizontal plane where light intensity arrive are perfectly defined according with the coordinate system explained in 4.1.4.

2) Previous rendering, Figure 17, is just a bitmap. So we need to import this image to Erdas Image software as a TIFF image and later to convert the image to the appropriated data file in order to be able to work with it. The extension of the data file that Erdas Image software works is .IMG. After that, we had to recognize the four ground control points (GCPs) in both of the image

using Image geometric correction option in the software. The referencing of the Style grey illuminance rendering was accomplished introducing the reference coordinates (X ref., Y ref.) and selecting the Polynomial Transformation order 1. This process creates a Transformation parameters which was used for the image rectification and its referencing.

3) Once the referencing process was completed and the Style grey illuminance render has assigned the exact coordinates system we can geometrically overlay and compare the results. The graphical comparison was realized by means of the overlapping between the referenced Style grey illuminance rendering and the Isolux diagram digitalisation²⁸ provided by Philips which we always use as an accurate reference data. The geometric overlapping result showed graphically is represented on the Figure 19.

4.2.2. ILLUMINANCE NUMERICAL VALUES FROM A AREA OF INTEREST.

ArcInfo was the tool used to verify the numerical results. These numerical results are the grey values (0-255) related to the illuminance values in each point. The main stages to complete the process were:

1) Firstly, we had to convert the Style Grey illuminance rendering to a grid²⁹ because we needed to work with the illuminance values contained on each cells. For this purpose we used the ArcInfo command:

```
IMAGEGRID <in_image> <out_grid | out_stack> {out_colormap_file} {in_band}
{NEAREST | BILINEAR | CUBIC} {DEFAULT | SQUARE}
```

To calculate the value of each output cell we used the Nearest option by assigning it the value of the nearest pixel in the input data.

2) The digitalisation process was stored in a Shapefile format. This is a vectorial data set. We needed to convert this shapefile to a grid to obtain the illuminance values in each point forming the digitalised isolux curve. For this purpose we used the ArcInfo command:

```
SHAPEGRID(<shapefile>, {item}, {cellsize})
```

where the shapefile is called *iso_lx.shp*, the item is *isoln_id* and the cell size is 0.066. The resulting grid was used like a mask to analyse this subset of cells considered as the area of interest³⁰. The mask contains the illuminance values in percentages according with the reference isolux diagram such as 50, 20, 10, 5 and 2. The output file grid was called *iso3*.

3) In order to apply the desired mask we used the ArcInfo command:

```
SAMPLE(<mask_grid>, {grid, ..., grid})
```

where the *mask_grid* is the grid which defines the cells to sample. The *grid argument* is the name of the grid whose values will be sampled based upon the mask grid. The following picture shows graphically the mask application over the illuminance grid.

²⁸ The digitalisation process gives as result a vector data-structure.

²⁹ A grid is based on a cell structure where each cell has a meaning. This structure uses rows and columns with X, Y coordinates to locate the position of each cell (Stuiver, 1999)

³⁰ Area of interest is a portion of a large grid over the desired cells.

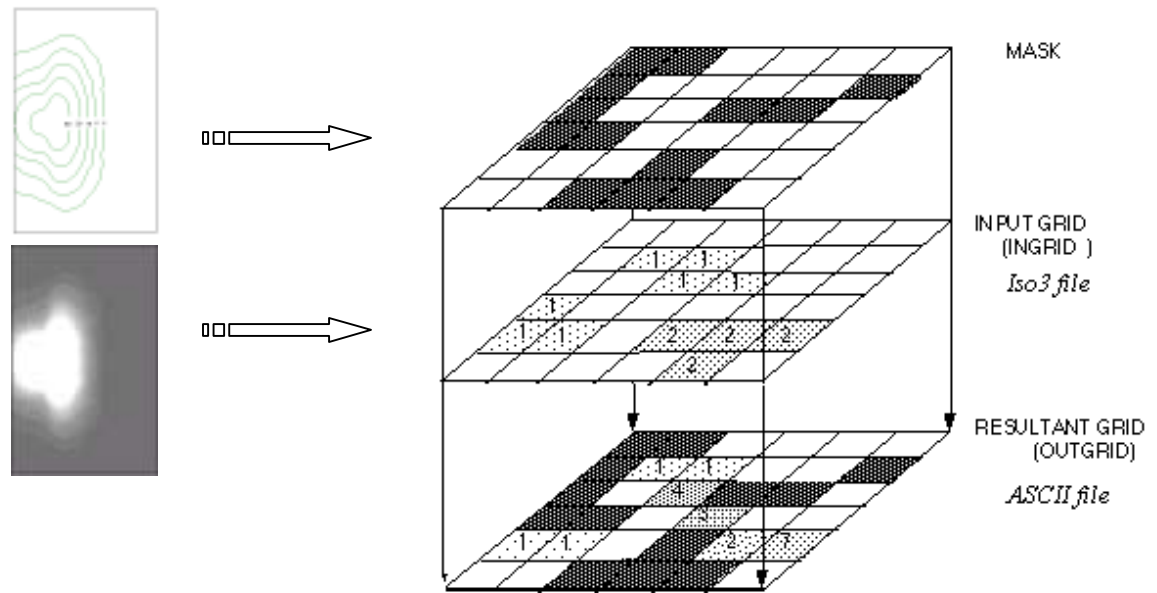


Fig. 18. Figure represents the mask grid application process over other grid file.

This operation creates an ASCII file listing the x and y coordinates of cells selected in the *mask_grid* and the respective cell values of the grid with their corresponding grey levels.

4.3. RESULTS

4.3.1. GEOMETRICAL COMPARISON.

We can see at next picture that the semblance and coincidence on the geometrical overlapping results is visually considerable.

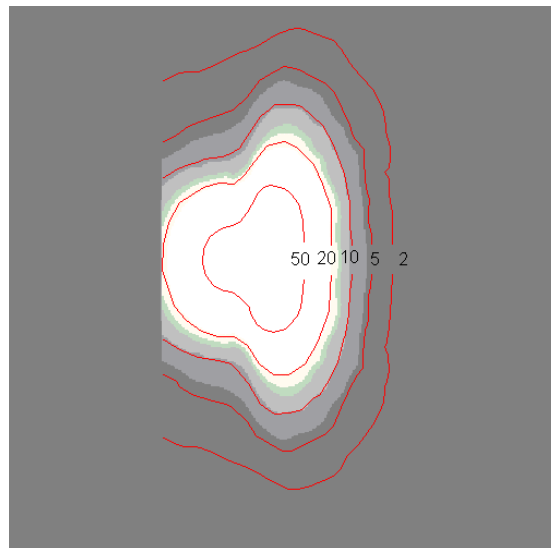


Fig. 19. Figure shows the geometric overlay between the digitalised reference islolux (represented by red lines) and the output illuminance rendering once was imported to Erdas image and referenced. Both of them in the same coordinates system.

4.3.2. NUMERICAL COMPARISON. STATISTIC STUDY.

The Statistic study was a illuminance numerical analysis of the values of the cells of the area of interest. So the theoretical values at the area of interest (where we are applied the mask) are showed at the following tables. The statistic study was realized using Excel package.

| MASK VALUES (GRID) | |
|--------------------|----------------------------------|
| Illuminance (%) | Real valour of Illuminance (lux) |
| 2 | 7.36 |
| 5 | 18.4 |
| 10 | 36.8 |
| 20 | 73.6 |
| 50 | 184 |
| 100 | 368 ³¹ |

| GREY VALUES | |
|-----------------|---------------------|
| Illuminnace (%) | Grey Levels (0-255) |
| 2 | 5.1 |
| 5 | 12.75 |
| 10 | 25.5 |
| 20 | 51.1 |
| 50 | 127.5 |
| 100 | 255 |

The first table shows the illuminance values regarding to the lineal scale represented on the Figure 15a. The illuminance maximum value is 368 luxes for the 100% if illuminance. So the rest of the values were calculated using the respectives percentages. The second table shows the grey levels related to the same percentages as the first table.

The Analysis statistic was accomplished taking the representative groups, that is, where we want to study the illuminance values. These groups were the following five:

1. The first group corresponds with 2% illuminance values. The obtained results are:

Table 3. Statistics summary over the illuminance values at the 2% group.

| FUNCTION | GREY LEVEL VALOUR | GREY LEVEL VALOUR | VALOUR FREQUENCY |
|--------------------|-------------------|-------------------|------------------|
| MEAN | 0.45513866 | 0 | 512 |
| STANDAR DESVIATION | 1.17017422 | 1 | 35 |
| MAX | 5 | 2 | 0 |
| MIN | 0 | 3 | 27 |
| | | 4 | 32 |
| | | 5 | 7 |
| | | Total: 613 | |

As we can see at the table the obtained grey level valour mean is 0.455. The most of the values are 0, concretely 521 of 613 values. For the illuminance values at the 2% group, the theoretical valour is 5.1 at the grey level and the obtained result was 0.455. So there is a significant difference with regards to the expected valour.

³¹ This valour is the Maximum Illuminance value according the reference Isolux diagram.

2. The second group corresponds with the 5% illuminance values. The obtained results are:

Table 4. Statistics summary over the illuminance values at the 5% group.

| FUNCTION | VALOUR | GREY LEVEL VALOUR | VALOUR FREQUENCY |
|---------------------------|--------|-------------------|------------------|
| <i>MEAN</i> | 10 | 10 | 586 |
| <i>STANDAR DESVIATION</i> | 0 | | |

All the obtained grey levels values in this group are 10. For the illuminance values at the 5% group, the grey level theoretical valour is 12.75 and the obtained result was 10. So this is a lower valour with regards to the expected.

3. The third group corresponds with the 10% illuminance values. The obtained results are:

Table 5. Statistics summary over the illuminance values at the 10% group.

| FUNCTION | GREY LEVEL VALOUR | GREY LEVEL VALOUR | VALOUR FREQUENCY |
|---------------------------|-------------------|-------------------|------------------|
| <i>MEAN</i> | 20.6215686 | 20 | 415 |
| <i>STANDAR DESVIATION</i> | 1.52900108 | 21 | 35 |
| <i>MAX</i> | 26 | 22 | 0 |
| <i>MIN</i> | 20 | 23 | 0 |
| | | 24 | 25 |
| | | 25 | 28 |
| | | 26 | 7 |
| | | | Total: 510 |

At this group the grey level valour mean is 20.62. The most of obtained grey levels in this group have valour of 20. According with the theoretical valour showed at the above table, it should correspond to 25.5. So the obtained valour is lower with regards to the expected again.

4. The fourth group corresponds with the 20% illuminance values. The obtained results are:

Table 6. Statistics summary over the illuminance values at the 20% group.

| FUNCTION | GREY LEVEL VALOUR | GREY LEVEL VALOUR | VALOUR FREQUENCY |
|---------------------------|-------------------|-------------------|------------------|
| <i>MEAN</i> | 45.513347 | 40 | 8 |
| <i>STANDAR DESVIATION</i> | 2.25606783 | 41 | 35 |
| <i>MAX</i> | 40 | 42 | 26 |
| <i>MIN</i> | 51 | 43 | 0 |
| | | 44 | 0 |
| | | 45 | 141 |
| | | 46 | 197 |
| | | 47 | 32 |
| | | | Total: 439 |

At this group the grey level valour mean is 45.51. The obtained grey levels in this group are really dispersed, being the most frequent values 45 and 46. According with the theoretical valour, it should correspond to 51.1. So the obtained valour is lower with regards to the expected again.

5. The fifth group corresponds with the 50% illuminance values. The obtained results are:

Table 7. Statistics summary over the illuminance values at the 50% group.

| FUNCTION | GREY LEVEL VALOUR | GREY LEVEL VALOUR | VALOUR FREQUENCY |
|--------------------|-------------------|-------------------|------------------|
| MEAN | 117.591696 | 107 | 2 |
| STANDAR DESVIATION | 4.57036805 | 108 | 7 |
| MAX | 128 | 109 | 7 |
| MIN | 107 | 112 | 12 |
| | | 113 | 32 |
| | | 114 | 29 |
| | | 117 | 58 |
| | | 118 | 52 |
| | | 119 | 17 |
| | | 122 | 20 |
| | | 123 | 27 |
| | | 124 | 10 |
| | | 127 | 9 |
| | | 128 | 7 |
| | | | Total: 289 |

At this group the grey level valour mean is 117.59. In this case the obtained values are quite dispersed with regards to the mean. According with the theoretical valour expected for this group, it should correspond to 127.5. Therefore, again the obtained valour is lower with regards to the expected.

4.3.2.1 SUMMARY TABLE AND CONCLUSIONS CASE.

Next table show the most relevant numerical results from the grey levels theoretical values and the obtained grey levels values.

Table 8. Statistics summary. Comparison between the theoretical values against the obtained values of the grey levels.

| Illuminance percentages | Computer pixel values | Observed mean pixel | Standard deviation |
|-------------------------|-----------------------|---------------------|--------------------|
| 2 | 5.1 | 0.455 | 1.17 |
| 5 | 12.75 | 10 | 0 |
| 10 | 25.5 | 20.6 | 1.53 |
| 20 | 51.1 | 45.51 | 2.256 |
| 50 | 127.5 | 117.59 | 4.57 |

We can appreciate at the table that the observed illuminance values always are too low compared with the computer pixel values (theoretic). If we paid attention on the observed mean values (third column), relatively the numerical results are acceptable (making exception with the 2% group). But, the observed numerical results in a absolute way are too low with regards to the computer pixel values.

The causes of the discrepancy between the computer pixel values and the obtained numerical results could have been next:

- The problem with the used grey scale. If we remind the section 4.1.5.1, the issue was that we didn't know the intermediate grey values and if their behaviour were completely lineal.
- The reference Isolux diagram provided by Philips.
- The internal mathematics computations of 3D Studio Max.

4.4. CONCLUSION

To carry out the verification of the 3D Studio Max rendering of light producing *Son Plus 150w* lamp and SGS203 armature I needed accurate input data and reference data. With the purpose to obtain physical basis results, IES file, Isolux diagram and Photometric data about the luminaire have been provided by Philips.

Most of the luminaire parameters are included on the corresponding IES file to the luminaire. So the parameters such as intensify, colour and others supported by IES file permitted us to define the lamp exactly with its photometric properties in 3D Studio Max.

After the representation of the luminaire, the reproduction of isolux diagram in 3D studio Max can be accomplished. To obtain this reproduction, in short the rendering of light of the Philips luminaire, we have to resort to a particulars coordinate system, scale and measures to simulate the graphic of the Isolux diagram provided by Philips. The fact is that the illuminance cannot be properly displayed and quantified unless we project the light on a horizontal plane with specific spatial dimensions, with the main objective of later comparison against the isolux diagram of Philips. Subsequently, the rendering of the amount arriving to the surface (Illuminance) from the luminaire can be realized using Pseudocolour tool. To emphasize that 3D Studio Max 5.1 has no provisions to measure light at user specified points, only pseudocolour maps of illuminance can be used for this purpose.

The important point is that the illuminance renderings produced by 3D Studio Max are simple bitmap images. For this reason, these renderings lose the coordinate system previously established, keeping only the dimensions. So the geo-referencing process has to be realized to overlay geometrically both diagrams (the digitalised isolux diagram and the illuminance rendering obtained by 3D Studio max). This geo-referencing was accomplished over the Grey Style (grey scale) and linear scale to make easier later calculus.

The statistics results verify that there is a discrepancy between the computer pixel values (theoretic) and the observed grey values (represented by the mean in each group). In spite of this discrepancy, the obtained values are considerable relatively acceptable. The absolutes values of the obtained grey levels are considered too low related to the expected theoretical values.

CHAPTER V. CONCLUSIONS AND DISCUSSIONS

The research process, literature-review and the obtained results in the previous chapter have contributed to the following conclusions, and some discussion points will also be describe.

5.1. GENERAL CONCLUSIONS

The following points answering the research questions rose at the first chapter.

1. Photometric lights in 3D Studio Max 5.1 can be represented defining a parameters set related to the used luminaire, such as luminous intensity, type of distribution, spectral colour lamp and the IES file (including others luminaire photometric characteristics).
2. The illuminance rendering from a light source in 3D Studio Max 5.1 can be verified. In this research, the Isolux diagram provided by Philips has been taken as the illuminance reference data. To verify illuminance rendering from a luminaire, the comparison between the pseudocolour illuminance rendering and the reference Isolux diagram of the same luminaire was accomplished as visual as numerically.
3. In this study, 3D Studio Max 5.1 have represented visually the emitted luminous flux from a single luminaire falling on a surface (illuminance) through an accurate illuminance mapping (the pseudocolour rendering). The illuminance values in this map are represented by a grey values scale lie between the maximum and minimum illuminance values. The main problem was to consider completely lineal the grey scale used in 3D Studio in order to calculate the illuminance values.
4. In order to carry out this study, data provided by Philips Company were:
 - Photometric technical data on the 203SGS armature and SON T PLUS 150w lamp corresponding to High-pressure sodium lamp.
 - IES standard format file of the same luminaire designed for Illumination Engineering Society of North America (IESNA) for a computational calculus.
 - The Isolux diagram of the same luminaire which represent the illuminance amount arriving to a surface. This is the reference data.

5.2. MAIN DISCUSSION POINTS

Through this research we have found with some specific discussion points which require a special attention and development. Those points are:

1. The three-dimensional photometric web represent the luminous intensity of a point source at the photometric centre of the lamp or luminaire for a determinate set of vertical and horizontal angles. The IES file in this research is composted on 37 vertical angles (between 0 and 180 degrees) and 27 horizontal angles (between 0 and 180 degrees). This angles indicate nodes direction of each one them, and theirs corresponding luminous intensity measured in candelas. So, the union of all nodes generates the discontinue three-dimensional figure called photometric web. This figure presents a coarse discretization. Besides, the system computes the luminous intensity along an arbitrary direction by interpolation. Completely opposite, the luminous intensity propagates through space in the real world. If we focus the attention on the illuminance

produced for the luminous intensity from a light source, it means that in later comparison between Isolux diagram provided by Philips and the reproduction illuminance rendering made by 3D Studio Max will produce discrepancies between both diagrams caused for the previously discussed.

2. An important discussing point is that we have to keep the photometric units in lumen to get physical result, that is, in practice we haven't changed the units to represent the luminous intensity from the luminaire once the IES file has been imported. The file structure is solid and, when file importation is produced all parameters are established, including the luminous intensity fixed in 16500 lm in this case (see 4.1.3.).

According with the Illuminance definition, luminous intensity arriving to the surface measured in luxes, seemed logical to think that in the intensity window of 3D Studio Max (see Figure 21) we would be able to have adapted the parameters regarding the Isolux diagram of the study luminaire, that is, $H=3$ meters and $E_{max}=368$ luxes. The experience showed using the luxes option the illuminance results didn't correspond with previously expected. 3D Studio Max interprets the intensity values provided by corresponding IES file and the software behaves as a "black box" when we tried changing to other any photometric units.

The achieved conclusion was to use lumen option because we know the rated power of the study luminaire, that is, 16500 lumens. This is the resulting intensity produced by the luminaire. So if we introduce 368 luxes as an intensity resulting (Figure 21b) we don't obtain the same result, because it is the maximum illuminance arriving to a surface according with the Philips isolux diagram.



Fig. 20. (a) The first window shows resulting intensity from the luminaire in lumens (16500 lm), as in the research has been used. (b) The second shows the parameters election with regards to the Isolux diagram ($H=3$ meters and $E_{max}=368$ luxes).

3. Other important point that we found in the research was the valour scale used by Pseudocolour exposure control. To realize the later illuminance values comparison between the 3D Studio Max rendering and the Philips diagram needed the numerical illuminance values. The only illuminance measurement available in 3D Studio is the valour scale. The decision of using the grey scale was because it is composed for only band (grey values lie between 0-255). This band have to be transformed to illuminance numerical values so it is easier than using the colored scale (using 3 bands). Closed to this point, we can discuss the reason of choosing the lineal scale. With the lineal scale could calculate illuminance values through a simple and easy way, using the known illuminance percentage and maximum values. But the important problem with the lineal scale is that we cannot claim behaves itself completely lineal at the intermediate values. After the statistic study about the theoretical grey levels against observed grey levels over a area of interest, we arrived to this conclusion observing the discrepancy among the values.

4. To achieve the main objective of this thesis, the verification of renderings of illuminance produced by 3D Studio Max 5.1 from the luminaire (provided by Philips), we have had to simulate a dimensionable space composed by a horizontal plane and the study luminaire. The

visualization and analysis was accomplished on a void environment and without taken in account the object's properties.

Then, the importance of using the spatial data in the 3D computer environment in order to achieve physical based lighting simulations should be to carry out a previous study about the environmental and object's physical properties. A standard material consists of ambient, diffuse, and specular components and it is possible to assign maps to the various components of a standard material. In 3D Studio Max can be defined the object physical properties through the Material Editor, at least with 12 properties such as Ambient colour, Diffuse colour, Specular colour, Specular level, Glossiness, Self-Illumination, opacity, Filter colour, Bump, Reflection, Refraction and displacement. Obviously, physically based model of material properties is somewhat different than the physical properties of a material. In lighting simulation applications, an important material characteristic to know is how much light energy a material reflects or transmits³² in order to obtain an accurate lighting simulation (Autodesk, 2002).

5. As it was said in the introduction of this research, Light pollution can occurs in the three following forms:

- *Sky glow.* Many light fixtures shine a large percentage of their light above the horizontal. The brightening of the skies through of poorly designed and improperly aimed light destroys sky view producing the bright orange glow seen over many cities. Accumulated sky glow from a small city can be seen many miles away, so this is not just a problem of direct glare. When light spills into the sky, it reflects off of tiny airborne dust and moisture particles.
- *Light Trespass.* The use of unshielded, badly aimed, poorly designed, or otherwise misapplied light fixtures results in wasted light shining into our yards and our windows. Spill light falling over property lines can illuminate adjacent grounds or buildings in an objectionable manner.
- *Glare.* Direct glare is defined as the visual discomfort resulting from insufficiently shielded light sources in the field of view that causes a reduction in visual performance or an irritation (mainly effects drivers and pedestrians) (GWU, 2001).

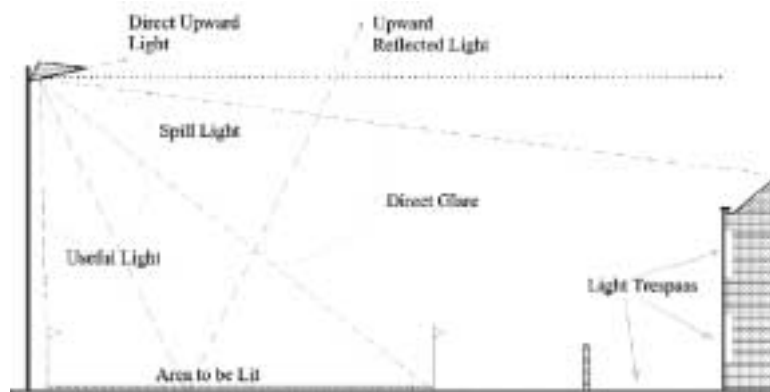


Fig.21. Figure shows the negative effects produced by a impropriety luminaire.

Those three forms to perform Light pollution have a difficult 3D simulation and modelling with a physical basis as consequence of the environment and atmospheric presence. The discussion of the possibilities and problems of modelling light pollution aspects in 3D Max 5.1 are summarize in the following table:

³² For example, a floor with a dark carpet may have a reflectance of 0.2, meaning that it reflects 20 percent of the light that it receives. Similarly a tinted window may have a transmittance of 0.75, meaning that 75 percent of the light that strikes the surface will be transmitted through it (the rest of the energy, in both cases, is absorbed).

| Light Pollution aspects | Can be modelled with 3D Studio Max | Verification | Problems |
|-------------------------|------------------------------------|--------------|---|
| Trespass | YES (1) | YES (2) | It needs object's properties and environment. |
| Glare | ?/YES (3) | ? (4) | It needs object's properties, environment and individual human experiences. |
| Sky glow | ? (5) | NO (6) | It needs object's properties, environment and atmospheric conditions. |

(1) The trespass problem can be modelled calculating the luminous flux arriving to the buildings and ground. It will be represent by vertical and horizontal illuminance.

(2) Verification can be possible because the horizontal an vertical illuminance could be measure with accurate instruments (photosensor).

(3) Glare can be measured by the Luminance parameter. Luminance is the basis to describing perceived brightness through the eyes.

(4) Glare is considered as a subjective problem causing a visual discomfort, so the verification of this aspect is really difficult.

(5) Sky glow could be modelled in 3D Studio Max but the great problem would be to represent the scattering of artificial light in the gases and particles of the air.

(6) Verification will be not possible using illuminance values.

Due to the huge amount of factors taking part in outdoor lighting and the human perception, calculus about this topic becomes really complexes. There are interesting possibilities for research. Nevertheless a complete physically based modelling of light pollution is a very complex task that may take too much effort.

APPENDIX I. GLOSSARY

1. Light terms and units. In lighting technology a number of technical terms and units are used to describe the physical properties of light and its corresponding units of measurements:

BRDF and BTDF

BRDF (bidirectional reflectance distribution function) and BTDF (bidirectional transmittance distribution function) measurements represent the ratio of illuminance (from a point source in a given direction) to luminance for an opaque (BRDF) or transparent (BTDF) surface. BRDF measurements are sometimes used by luminaire manufacturers to mathematically model semi-specular reflectors, such as brushed aluminum. Recent developments in advanced optical materials such as *kinofom diffusers* will make both BRDF and BTDF measurements more important for luminaire designers (Ian Ashdown, 2001).

Candela

The candela is the primary basic unit in lighting technology from which all others are derived. The candela was originally defined by the luminous intensity of a standardized candle. Later thorium powder at the temperature of the solidification of platinum was defined as the standard; since 1979 the candela has been defined by a source of radiation that radiates 1/683 W per steradian at a frequency of $540 \cdot 10^{12}$ Hz (Ganslandt et al., 1992).

Colour

What we perceive as colour are photons with different wavelengths, ranging from approximately 400 nanometres (blue) to 700 nanometres (red). Our eyes have a peak sensitivity at 555 nanometres (green). Colour is rarely considered in photometric measurements. However, the recent availability of lighting design and analysis software that includes colour in its visualization capabilities has heightened designers' interest in this topic (Ian Ashdown, 2001).

Exposure

Exposure is described as the product of the illuminance and the exposure time. Exposure is an important issue, for example, regarding the calculating of light exposure on exhibits in museums (Ganslandt et al., 1992).

Goniophotometry

Goniophotometry is the measurement of the luminous intensity of a light source from different directions.

A goniophotometer consists of a mechanical device to support and optionally position the light source (a luminaire or lamp) and a photosensor, together with associated electrical and electronic equipment to acquire and process the photometric data (Ian Ashdown, 2001).

Illuminance

Illuminance indicates the amount of luminous flux from a light source falling on a given area, divided by the area of the surface. It is measured in either *footcandles* (lumens per square foot, AS units) or *lux* (lumens per square meter, SI units). Illuminance decreases with the square of the distance from the light source (*inverse square law*).

We can measure illuminance with an incident light meter. The photosensor absorbs light incident upon its surface and converts into an electrical current (Ian Ashdown, 2001).

Inverse square law

The illumination at a point in a plane is proportional to the luminous intensity, and inversely proportional to the square of the distance from the light source (Ganslandt et al., 1992).

Light

Light is *electromagnetic energy*, which includes radio waves, microwaves, infrared, visible, ultraviolet, X-rays and gamma rays. We can think of it as subatomic particles (called *photons*) flowing through space in all directions. Each photon has a certain energy that is determined by its wavelength.

More usefully, we can think of light as the *flow* of electromagnetic energy – so many photons per second, similar in principle to the flow of electrical current. For visible light, this flow is measured in lumens (Ian Ashdown, 2001).

Lumen

A unit of measure of the quantity of light. One lumen is the amount of light which falls on an area of one square foot every point of which is one foot from the source of 1 candela (Ganslandt et al., 1992).

Luminance

Whereas illuminance indicates the amount of luminous flux falling on a given surface, luminance describes the brightness of an illuminated or luminous surface. Luminance is defined as the ratio of luminous intensity of a surface (cd) to the projected area of this surface (m²). In the case of illumination the light can be reflected by the surface or transmitted through the surface. In the case of diffuse reflecting (matt) and diffuse transmitting (opaque) materials luminance can be calculated from the illuminance and the reflectance or transmittance. Luminance is the basis for describing perceived brightness; the actual brightness is, however, still influenced by the state of adaptation of the eye, the surrounding contrast ratios and the information content of the perceived surface. Luminance is measured in candelas per square meter or candelas per square inch (Ganslandt et al., 1992).

Luminous efficacy

Luminous efficacy describes the luminous flux of a lamp in relation to its power consumption and is therefore expressed in lumen per watt (lm/W). The maximum value theoretically attainable when the total radiant power is transformed into visible light is 683 lm/W. Luminous efficacy varies from light source to light source, but always remains well below this optimum value. For example, a 100-watt lamp producing 1750 lumens gives 17.5 lumens per watt. Example:

| | |
|-----------------------------|------------|
| Edison's first lamp: | 1.4 lpw |
| Incandescent lamp: | 10-40 lpw |
| Fluorescent lamps: | 35-104 lpw |
| Halogen lamps: | 20-45 lpw |
| Mercury lamps: | 37-63 lpw |
| Metal halide lamps: | 80-125 lpw |
| High pressure sodium lamps: | 54-153 lpw |

Luminous flux

Luminous flux describes the total amount of light emitted by a light source. This radiation could basically be measured or expressed in watt. This does not, however, describe the optical effect of a light source adequately, since the varying spectral sensitivity of the eye is not taken into account. To include the spectral sensitivity of the eye the luminous flux is measured in *lumen*.

Luminous flux is the quantity of light energy per unit time arriving, leaving, or going through a surface. The lumen (lm) is the unit of luminous flux in both the International System (SI) of units and in the American System (AS) of units. If you think of light as particles (photons) moving through space, then the luminous flux of a light beam arriving at a surface is proportional to the number of particles hitting the surface during a time interval of 1 second (Ganslandt et al., 1992).

Luminous intensity

An ideal point-source lamp radiates luminous flux uniformly into the space in all directions; its luminous intensity is the same in all directions. In practice, however, luminous flux is not distributed uniformly. This results partly from the design of the light source, and partly on the way the light is intentionally directed. It makes sense, therefore, to have a way of presenting the spatial distribution of luminous flux, i.e. the luminous intensity distribution of the light source. The unit for measuring luminous intensity is candela (cd).

Luminous intensity is the light energy per unit time emitted by a point source in a particular direction. Luminous intensity is used to describe the directional distribution of a light source, that is, to specify how the luminous intensity of a light source varies as a function of the outgoing direction. The Candela (cd) is the unit of luminous intensity (Ganslandt et al., 1992).

Lux

The International System (SI) unit of illumination. The illumination produces on a surface 1 meter or 1 foot from a light source of 1 cd luminous intensity, measured in a plane perpendicular to the direction of radiation is defined as Lux (Ganslandt et al., 1992).

Quantity of light

The quantity of light, or luminous energy, is a product of the luminous flux emitted multiplied by time; luminous energy is generally expressed in klm · h (Ganslandt et al., 1992).

Watts

The amount of energy needed to power a light source (Ganslandt et al., 1992).

2. Equipments terms. Current terminology relating to hardware and its mounting include the following:

Ballast

A device used to step up voltage and amperage to a light source. It is necessary for most outdoor lighting sources (excluding incandescent) (Ganslandt et al., 1992).

Horizontal Cut Off

A light fixture that does not allow the to shine above 90° of the lowest point of the light fixture (Ganslandt et al., 1992).

Ignitor

Control gear which promotes the ignition of discharge lamps by producing high-voltage peaks. Leakage transformers, ignition transformers, ignition pulsers and electronic ignitors can be used as igniters light source (Ganslandt et al., 1992).

Lamp

Technical term for a light source (often a light bulb) (Ganslandt et al., 1992).

Light Fixture

The hardware that holds a lamp; the design of the fixture determines where the light from the lamp shines (Ganslandt et al., 1992).

Lighting Efficiency

How much electricity is needed to properly light an area. Consists of two factors: the type of light fixture and type of lamp used (Ganslandt et al., 1992).

Luminaire

A complete lighting unit consisting of a lamp or lamps together with the parts designed to distribute the light, to position and protect the lamps and to connect the lamps to the power supply (Ganslandt et al., 1992).

Mounting Height

The vertical distance between the roadway surface and the centre of the apparent light source of the luminaire (Ganslandt et al., 1992).

3. The general types of lamps presently in use for roadway lighting are the following:

Fluorescent lamp

Low-pressure discharge lamp filled with mercury vapour. The ultraviolet radiation produced during the mercury discharge process is converted into visible light by the luminous substances on the inner wall of the discharge tube. By using different luminous substances it is possible to produce a variety of luminous colours and different colour rendering qualities. As a rule, fluorescent lamps have heated electrodes and can therefore be ignited at comparatively low voltages. Fluorescent lamps require an ignitor and a ballast (Ganslandt et al., 1992).

Halogen lamp

Compact incandescent lamp with additional halides in the gas compound, which prevents deposits of the evaporated filament material forming on the outer envelope. In contrast to general service lamps, halogen lamps have increased luminous efficacy and a longer service life (Ganslandt et al., 1992).

High-pressure mercury lamp

The mercury lamp replaced the incandescent lamp in popularity. The initial cost is higher and it requires a ballast, but its high efficacy and long life make it considerably more attractive than the incandescent lamp. High-pressure discharge lamp containing mercury vapour. In contrast to the low-pressure discharge process, which produces almost exclusively ultraviolet radiation, at high pressure mercury vapour produces visible light with a low red content. Luminous substances can be added to complement the red content and improve colour rendering. High-pressure mercury lamps require ballasts, but no ignitors (Ganslandt et al., 1992).

High-pressure sodium lamp

High-pressure discharge lamp containing sodium vapour. As aggressive sodium vapour can destroy glass at high pressures, the internal discharge tube is made of alumina ceramic and surrounded by an additional outer envelope. In contrast to low-pressure sodium lamps colour rendition is considerably improved, but at the expense of luminous efficacy. The luminous colour is in the warm white range. High-pressure sodium lamps require ignitors and ballasts. The high pressure sodium Cut-off system is the most energy efficient and will often require fewer posts, thus resulting in lower energy and maintenance costs. However, the colour properties of high

pressure sodium are only fair and should be used when colour rendering is not critical (Ganslandt et al., 1992).

Incandescent lamps

The incandescent or filament lamp was for many years the most commonly used. However, its low efficacy and short rated life have made it undesirable for many installations. It is composed by a thermal radiator, where light is produced by the heating of a wire filament (usually tungsten). The filament is contained in an outer envelope made of glass and filled with a special gas (nitrogen or inert gas) to prevent the filament from oxidizing and to slow down the vaporization of the filament material. There are various types of incandescent lamps available: the main group comprises general purpose lamps with drop-shaped, clear or frosted outer envelopes, the reflector lamp with a variety of internal mirrors, and the PAR lamp made of pressed glass with an integral parabolic reflector (Ganslandt et al., 1992).

Low-pressure sodium lamp

Low-pressure discharge lamp containing sodium vapour. The internal discharge tube is surrounded by an outer envelope that reflects infrared radiation to increase the lamp temperature. Low-pressure sodium lamps have excellent luminous efficacy. As they emit monochromatic, yellow light, it is not possible to recognize colours under the lighting provided by these lamps. Low-pressure sodium lamps require ignitors and ballast (Ganslandt et al., 1992).

Metal halide lamp

High-pressure discharge lamp where the envelope is filled with metal halides. In contrast to pure metals, halogen compounds melt at a considerably lower temperature. This means that metals that do not produce metal vapour when the lamp is in operation can also be used. The availability of a large variety of source materials means that metal vapour compounds can be produced which in turn produce high luminous efficacy during the discharge process, and good colour rendering (Ganslandt et al., 1992).

APPENDIX II. IES FILES FORMAT

The IES file is directly connected with the distribution photometric of each light source. A photometry file or report is a matrix of values which define the performance of a specific luminaire with a specific lamp installed. In the follow file is possible to see the detailed information about the used angles (horizontal and vertical) and the emitted flux (lumens) of 203SGS luminaire and the Son Plus 150w lamp.

Ies file notes

1. The photometric data is stored in ASCII format.
2. The maximum length of any label / keyword line is 82 characters. The maximum length of any other line is 132 characters and must be terminated by a carriage return/line-feed character sequence.
3. Label lines (02 to 05 inclusive) contain descriptive text about the luminaire, the lamp(s) used, and other descriptive comments.
4. Each label line begins with a defined IES keyword in square brackets. (User-defined keywords are also permitted). Each field in the file must begin on a new line and must appear exactly in the following sequence:

```

IESNA:LM-63-1995
[TEST] LVA2033200
[MANUFAC] PHILIPS
[LUMCAT] Database version IES95 2003-07-14
[LUMINAIRE] SGS203/150T P.1
[LAMP] SON-TP150W
[BALLAST] Standard
[OTHER] B-Angle = 0.00 B-Tilt = 0.00
TILT=NONE
1 16500.00 1 37 27 1 2 0 0 0
1.0 1.0 168.00
  0.00 10.00 20.00 30.00 35.00 40.00 45.00 47.50 50.00 52.50
  55.00 57.50 60.00 62.50 65.00 67.50 70.00 72.50 75.00 77.50
  80.00 82.50 85.00 87.50 90.00 92.50 95.00 97.50 100.00 102.50
105.00 110.00 120.00 135.00 150.00 165.00 180.00
  0.00 15.00 30.00 40.00 45.00 50.00 55.00 60.00 65.00 70.00
  75.00 80.00 85.00 90.00 95.00 100.00 105.00 110.00 115.00 120.00
125.00 130.00 135.00 140.00 150.00 165.00 180.00
  2227.50 2574.00 3762.00 4702.50 5016.00 4636.50 3960.00
  4092.00 3894.00 3333.00 2871.00 2607.00 2161.50 1551.00
  1089.00 627.00 330.00 214.50 132.00 115.50 82.50
  66.00 49.50 33.00 16.50 16.50 16.50 16.50
  16.50 16.50 0.00 0.00 0.00 0.00 0.00
  0.00 0.00
  2227.50 2722.50 3778.50 4108.50 4273.50 3976.50 3927.00
  4207.50 4290.00 3811.50 3217.50 2772.00 2458.50 2112.00
  1683.00 990.00 478.50 379.50 297.00 214.50 99.00
  66.00 33.00 33.00 16.50 16.50 16.50 16.50
  16.50 16.50 0.00 0.00 0.00 0.00 0.00
  0.00 0.00
  2227.50 2656.50 3267.00 3795.00 4240.50 4603.50 4488.00
  4818.00 5214.00 4999.50 4174.50 3531.00 2854.50 2409.00
  1947.00 1369.50 1023.00 858.00 693.00 610.50 231.00
  82.50 82.50 82.50 49.50 82.50 115.50 33.00
  16.50 16.50 16.50 16.50 0.00 0.00 0.00
  0.00 0.00
  2227.50 2442.00 2937.00 3696.00 4257.00 4603.50 4983.00

```


Graphical material

| | | | | | | |
|---------|---------|---------|---------|---------|---------|---------|
| 5115.00 | 5263.50 | 5412.00 | 5379.00 | 4752.00 | 4141.50 | 4092.00 |
| 3366.00 | 2854.50 | 2392.50 | 1798.50 | 1485.00 | 1171.50 | 379.50 |
| 115.50 | 82.50 | 66.00 | 49.50 | 49.50 | 115.50 | 132.00 |
| 99.00 | 82.50 | 33.00 | 16.50 | 0.00 | 0.00 | 0.00 |
| 0.00 | 0.00 | | | | | |
| 2227.50 | 2359.50 | 2871.00 | 3663.00 | 4356.00 | 4620.00 | 5263.50 |
| 5494.50 | 5610.00 | 5643.00 | 5659.50 | 4900.50 | 4686.00 | 4752.00 |
| 4092.00 | 3514.50 | 2970.00 | 2244.00 | 1864.50 | 924.00 | 231.00 |
| 115.50 | 82.50 | 49.50 | 49.50 | 49.50 | 99.00 | 132.00 |
| 132.00 | 66.00 | 33.00 | 16.50 | 0.00 | 0.00 | 0.00 |
| 0.00 | 0.00 | | | | | |
| 2227.50 | 2277.00 | 2755.50 | 3514.50 | 4125.00 | 4504.50 | 5362.50 |
| 5511.00 | 5709.00 | 5857.50 | 5692.50 | 5230.50 | 5197.50 | 5395.50 |
| 4900.50 | 4389.00 | 3861.00 | 2772.00 | 2326.50 | 1237.50 | 247.50 |
| 115.50 | 82.50 | 49.50 | 33.00 | 49.50 | 66.00 | 66.00 |
| 66.00 | 49.50 | 16.50 | 16.50 | 0.00 | 0.00 | 0.00 |
| 0.00 | 0.00 | | | | | |
| 2227.50 | 2227.50 | 2623.50 | 3382.50 | 3910.50 | 4455.00 | 5395.50 |
| 5626.50 | 5758.50 | 6072.00 | 5775.00 | 5461.50 | 5841.00 | 5626.50 |
| 5610.00 | 5214.00 | 4521.00 | 3448.50 | 2557.50 | 1023.00 | 198.00 |
| 115.50 | 82.50 | 49.50 | 33.00 | 33.00 | 33.00 | 33.00 |
| 33.00 | 16.50 | 16.50 | 16.50 | 0.00 | 0.00 | 0.00 |
| 0.00 | 0.00 | | | | | |
| 2227.50 | 2145.00 | 2442.00 | 3168.00 | 3646.50 | 4174.50 | 5263.50 |
| 5527.50 | 5610.00 | 5973.00 | 5923.50 | 5676.00 | 5989.50 | 5857.50 |
| 6072.00 | 6220.50 | 5626.50 | 4620.00 | 3151.50 | 1452.00 | 264.00 |
| 132.00 | 99.00 | 66.00 | 33.00 | 33.00 | 33.00 | 33.00 |
| 33.00 | 16.50 | 16.50 | 16.50 | 0.00 | 0.00 | 0.00 |
| 0.00 | 0.00 | | | | | |
| 2227.50 | 2112.00 | 2293.50 | 2920.50 | 3366.00 | 3811.50 | 5032.50 |
| 5181.00 | 5362.50 | 5758.50 | 5808.00 | 5610.00 | 5907.00 | 5643.00 |
| 6204.00 | 6715.50 | 6088.50 | 5098.50 | 3399.00 | 1204.50 | 264.00 |
| 132.00 | 99.00 | 66.00 | 33.00 | 33.00 | 33.00 | 33.00 |
| 16.50 | 16.50 | 16.50 | 16.50 | 0.00 | 0.00 | 0.00 |
| 0.00 | 0.00 | | | | | |
| 2227.50 | 2095.50 | 2145.00 | 2508.00 | 2772.00 | 3118.50 | 4207.50 |
| 4339.50 | 4702.50 | 5065.50 | 5412.00 | 5131.50 | 5362.50 | 5181.00 |
| 5643.00 | 6501.00 | 6303.00 | 5643.00 | 4092.00 | 1848.00 | 396.00 |
| 148.50 | 115.50 | 99.00 | 33.00 | 33.00 | 33.00 | 16.50 |
| 16.50 | 16.50 | 16.50 | 16.50 | 0.00 | 0.00 | 0.00 |
| 0.00 | 0.00 | | | | | |
| 2227.50 | 2079.00 | 2079.00 | 2260.50 | 2392.50 | 2640.00 | 3069.00 |
| 3250.50 | 3630.00 | 4240.50 | 4554.00 | 4438.50 | 4488.00 | 4537.50 |
| 4834.50 | 5791.50 | 5808.00 | 5115.00 | 3828.00 | 1567.50 | 330.00 |
| 148.50 | 115.50 | 82.50 | 33.00 | 33.00 | 33.00 | 16.50 |
| 16.50 | 16.50 | 16.50 | 16.50 | 0.00 | 0.00 | 0.00 |
| 0.00 | 0.00 | | | | | |
| 2227.50 | 2062.50 | 2013.00 | 2079.00 | 2145.00 | 2277.00 | 2442.00 |
| 2475.00 | 2590.50 | 2854.50 | 2937.00 | 3003.00 | 3102.00 | 3316.50 |
| 3448.50 | 4092.00 | 4306.50 | 3976.50 | 3118.50 | 1501.50 | 346.50 |
| 148.50 | 115.50 | 99.00 | 33.00 | 33.00 | 16.50 | 16.50 |
| 16.50 | 16.50 | 16.50 | 16.50 | 0.00 | 0.00 | 0.00 |
| 0.00 | 0.00 | | | | | |
| 2227.50 | 2046.00 | 1980.00 | 2013.00 | 2062.50 | 2145.00 | 2145.00 |
| 2145.00 | 2211.00 | 2277.00 | 2293.50 | 2293.50 | 2277.00 | 2343.00 |
| 2475.00 | 2623.50 | 2722.50 | 2409.00 | 1584.00 | 643.50 | 198.00 |
| 115.50 | 99.00 | 82.50 | 33.00 | 16.50 | 16.50 | 16.50 |
| 16.50 | 16.50 | 16.50 | 16.50 | 0.00 | 0.00 | 0.00 |
| 0.00 | 0.00 | | | | | |
| 2227.50 | 2029.50 | 1947.00 | 1914.00 | 2013.00 | 2095.50 | 2079.00 |
| 2079.00 | 2112.00 | 2161.50 | 2161.50 | 2128.50 | 2095.50 | 2079.00 |
| 2095.50 | 2145.00 | 2128.50 | 1798.50 | 1089.00 | 412.50 | 181.50 |
| 115.50 | 99.00 | 82.50 | 16.50 | 16.50 | 16.50 | 16.50 |

Graphical material

| | | | | | | |
|---------|---------|---------|---------|---------|---------|---------|
| 16.50 | 16.50 | 16.50 | 16.50 | 0.00 | 0.00 | 0.00 |
| 0.00 | 0.00 | | | | | |
| 2227.50 | 2029.50 | 1947.00 | 1897.50 | 1947.00 | 2013.00 | 2029.50 |
| 2062.50 | 2079.00 | 2112.00 | 2128.50 | 2112.00 | 2062.50 | 2046.00 |
| 2029.50 | 2013.00 | 1947.00 | 1650.00 | 924.00 | 346.50 | 165.00 |
| 115.50 | 99.00 | 82.50 | 16.50 | 16.50 | 16.50 | 16.50 |
| 16.50 | 16.50 | 16.50 | 16.50 | 0.00 | 0.00 | 0.00 |
| 0.00 | 0.00 | | | | | |
| 2227.50 | 2029.50 | 1930.50 | 1864.50 | 1914.00 | 1963.50 | 1996.50 |
| 2013.00 | 2046.00 | 2079.00 | 2128.50 | 2095.50 | 2079.00 | 2062.50 |
| 1996.50 | 1897.50 | 1831.50 | 1452.00 | 693.00 | 231.00 | 115.50 |
| 99.00 | 82.50 | 66.00 | 16.50 | 16.50 | 16.50 | 16.50 |
| 16.50 | 16.50 | 16.50 | 16.50 | 0.00 | 0.00 | 0.00 |
| 0.00 | 0.00 | | | | | |
| 2227.50 | 2029.50 | 1914.00 | 1881.00 | 1864.50 | 1996.50 | 1980.00 |
| 1980.00 | 1996.50 | 2029.50 | 2062.50 | 2095.50 | 2046.00 | 2079.00 |
| 2029.50 | 1864.50 | 1765.50 | 1617.00 | 858.00 | 297.00 | 115.50 |
| 82.50 | 66.00 | 66.00 | 16.50 | 16.50 | 16.50 | 16.50 |
| 16.50 | 16.50 | 16.50 | 16.50 | 0.00 | 0.00 | 0.00 |
| 0.00 | 0.00 | | | | | |
| 2227.50 | 2013.00 | 1897.50 | 1930.50 | 1864.50 | 1947.00 | 1980.00 |
| 1980.00 | 1996.50 | 2013.00 | 2029.50 | 2046.00 | 2013.00 | 2013.00 |
| 1980.00 | 1765.50 | 1650.00 | 1551.00 | 775.50 | 231.00 | 99.00 |
| 82.50 | 66.00 | 49.50 | 33.00 | 16.50 | 16.50 | 16.50 |
| 16.50 | 16.50 | 16.50 | 16.50 | 0.00 | 0.00 | 0.00 |
| 0.00 | 0.00 | | | | | |
| 2227.50 | 2013.00 | 1897.50 | 1963.50 | 1930.50 | 1947.00 | 1947.00 |
| 1963.50 | 1996.50 | 2013.00 | 2013.00 | 1996.50 | 1930.50 | 1947.00 |
| 1914.00 | 1798.50 | 1567.50 | 1501.50 | 1056.00 | 297.00 | 115.50 |
| 66.00 | 66.00 | 49.50 | 33.00 | 33.00 | 33.00 | 16.50 |
| 16.50 | 16.50 | 16.50 | 16.50 | 16.50 | 0.00 | 0.00 |
| 0.00 | 0.00 | | | | | |
| 2227.50 | 2013.00 | 1897.50 | 1963.50 | 1897.50 | 1947.00 | 1930.50 |
| 1947.00 | 1980.00 | 1947.00 | 1963.50 | 1930.50 | 1831.50 | 1831.50 |
| 1765.50 | 1699.50 | 1501.50 | 1402.50 | 1023.00 | 280.50 | 99.00 |
| 66.00 | 66.00 | 49.50 | 33.00 | 33.00 | 49.50 | 49.50 |
| 66.00 | 16.50 | 16.50 | 16.50 | 16.50 | 0.00 | 0.00 |
| 0.00 | 0.00 | | | | | |
| 2227.50 | 2046.00 | 1914.00 | 1980.00 | 1897.50 | 1897.50 | 1831.50 |
| 1881.00 | 1864.50 | 1897.50 | 1831.50 | 1815.00 | 1782.00 | 1749.00 |
| 1683.00 | 1617.00 | 1518.00 | 1336.50 | 1138.50 | 577.50 | 115.50 |
| 82.50 | 66.00 | 49.50 | 49.50 | 33.00 | 33.00 | 33.00 |
| 33.00 | 33.00 | 33.00 | 33.00 | 16.50 | 0.00 | 0.00 |
| 0.00 | 0.00 | | | | | |
| 2227.50 | 2029.50 | 1930.50 | 1980.00 | 1914.00 | 1963.50 | 1881.00 |
| 1831.50 | 1864.50 | 1848.00 | 1815.00 | 1732.50 | 1716.00 | 1633.50 |
| 1567.50 | 1485.00 | 1402.50 | 1221.00 | 957.00 | 495.00 | 132.00 |
| 82.50 | 66.00 | 99.00 | 99.00 | 66.00 | 49.50 | 33.00 |
| 33.00 | 16.50 | 16.50 | 16.50 | 0.00 | 0.00 | 0.00 |
| 0.00 | 0.00 | | | | | |
| 2227.50 | 2062.50 | 1930.50 | 1980.00 | 1897.50 | 1881.00 | 1881.00 |
| 1798.50 | 1815.00 | 1815.00 | 1749.00 | 1666.50 | 1584.00 | 1551.00 |
| 1468.50 | 1402.50 | 1320.00 | 1138.50 | 858.00 | 544.50 | 165.00 |
| 99.00 | 82.50 | 82.50 | 82.50 | 66.00 | 82.50 | 82.50 |
| 82.50 | 66.00 | 66.00 | 33.00 | 0.00 | 0.00 | 0.00 |
| 0.00 | 0.00 | | | | | |
| 2227.50 | 2062.50 | 1963.50 | 1963.50 | 1881.00 | 1815.00 | 1765.50 |
| 1765.50 | 1716.00 | 1699.50 | 1617.00 | 1567.50 | 1518.00 | 1468.50 |
| 1419.00 | 1336.50 | 1171.50 | 973.50 | 693.00 | 396.00 | 148.50 |
| 99.00 | 99.00 | 99.00 | 82.50 | 66.00 | 66.00 | 66.00 |
| 66.00 | 49.50 | 49.50 | 16.50 | 0.00 | 0.00 | 0.00 |
| 0.00 | 0.00 | | | | | |
| 2227.50 | 1980.00 | 1980.00 | 1914.00 | 1798.50 | 1782.00 | 1699.50 |

Graphical material

| | | | | | | |
|---------|---------|---------|---------|---------|---------|---------|
| 1683.00 | 1683.00 | 1650.00 | 1584.00 | 1485.00 | 1435.50 | 1369.50 |
| 1287.00 | 1171.50 | 957.00 | 742.50 | 478.50 | 247.50 | 132.00 |
| 115.50 | 99.00 | 99.00 | 82.50 | 66.00 | 49.50 | 49.50 |
| 33.00 | 33.00 | 16.50 | 0.00 | 0.00 | 0.00 | 0.00 |
| 0.00 | 0.00 | | | | | |
| 2227.50 | 1930.50 | 2029.50 | 1963.50 | 1815.00 | 1699.50 | 1617.00 |
| 1584.00 | 1551.00 | 1468.50 | 1353.00 | 1254.00 | 1155.00 | 1089.00 |
| 973.50 | 808.50 | 610.50 | 429.00 | 280.50 | 148.50 | 115.50 |
| 82.50 | 66.00 | 66.00 | 49.50 | 33.00 | 16.50 | 16.50 |
| 16.50 | 16.50 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 0.00 | 0.00 | | | | | |
| 2227.50 | 2161.50 | 2145.00 | 2013.00 | 1930.50 | 1831.50 | 1732.50 |
| 1699.50 | 1650.00 | 1551.00 | 1452.00 | 1336.50 | 1254.00 | 1122.00 |
| 990.00 | 858.00 | 693.00 | 495.00 | 297.00 | 148.50 | 115.50 |
| 99.00 | 82.50 | 82.50 | 66.00 | 49.50 | 16.50 | 16.50 |
| 16.50 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 0.00 | 0.00 | | | | | |

APPENDIX III. CHARACTERISTICS OF A LUMINAIRE

Next information describes all characteristics of the luminaire (203SGS armature and Son Plus 150w lamp) normally used with Son Plus 150w lamp.

Road lighting

F/H/K/S/MGS 203/403



| Type | Lamp | Weight kg | Ordering number |
|--|--------------------|-----------|-----------------|
| Luminaires with polyester canopy with gear | | | |
| HGS 203042 | PL-T4P 42W | 4.4 | 9105 000 9081B |
| HGS 203080-125G | HPL-N 80W/125W | 5.5 | 9105 000 4631B |
| HGS 203050B4 | QL 55W | 5.4 | 9105 000 4181B |
| SGS 203050G | SON 50W I | 5.4 | 9105 000 4191B |
| SGS 203070G | SON 70W I | 5.7 | 9105 000 4981B |
| SGS 203070G SN | SON(-T) PLUS 70W | 5.7 | 9105 000 4321B |
| SGS 203100G SN | SON(-T) PLUS 100W | 6.6 | 9105 000 4331B |
| SGS 203150G SN | SON(-T) PLUS 150W | 6.9 | 9105 000 4391B |
| SGS 203060-60 | PL-T 60W | 6.7 | 9105 000 4411B |
| SGS 203060-90 | PL-T 90W | 7.6 | 9105 000 4421B |
| Luminaires with aluminium canopy with gear | | | |
| HGS 403042 | PL-T4P 42W | 5.4 | 9104 018 1001B |
| HGS 403080-125G | HPL-N 80W/125W | 6.5 | 9105 000 9571B |
| HGS 403050B4 | QL 55W | 6.4 | 9105 000 9531B |
| SGS 403050G | SON 50W I | 6.4 | 9104 018 1181B |
| SGS 403070G | SON 70W I | 6.7 | 9105 000 9581B |
| SGS 403070G SN | SON (-T PLUS) 70W | 6.7 | 9105 000 9501B |
| SGS 403100G SN | SON (-T PLUS) 100W | 7.6 | 9105 000 9551B |
| SGS 403150G SN | SON (-T PLUS) 150W | 7.9 | 9105 000 9481B |
| HGS 403070G SN | CDM-T 70W | 6.7 | 9104 018 1051B |
| HGS 403150G SN | CDM-T 150W | 7.9 | 9104 018 1171B |
| Luminaires with polyester canopy with empty gear tray | | | |
| HYS-S 2031127 | | 4.1 | 9105 000 4541B |
| SGS 203040 | | 4.2 | 9105 000 4531B |
| Luminaires with aluminium canopy with empty gear tray | | | |
| HYS-S 4031127 | | 5.1 | 9104 018 1161B |
| SGS 403040 | | 5.2 | 9104 018 1151B |
| Mounting brackets | | | |
| ZGP 34 (34 mm) | | 0.3 | 9119 114 2281B |
| ZGP 42-48 (42-48 mm) | | 0.3 | 9119 114 0051B |
| ZGP 60 (60 mm) | | 0.3 | 9119 114 0061B |
| ZGP 76 (76 mm post top) | | 0.5 | 9119 114 0071B |

All units are equipped with 230V50Hz gear. Other voltages. Self-stopping ignitors. Dimming gear. Photocell and/or Class II versions are available on request.

H/SGS 203

Low-power, modular luminaires in contemporary style giving quality lighting for safe and comfortable driving and for area illumination with low energy and maintenance costs. Grey glass-fibre reinforced polyester or high-pressure diecast aluminium canopy, choice of high impact resistant UV stabilized polycarbonate bowl or minimal-glare flat security glass. Choice of lamps includes extra-long-life QL, PL-T, high-pressure mercury high-pressure sodium and mastercolours.

Main applications

- Residential areas
- Car parks
- Major roads
- Secondary roads
- Local roads
- Industrial areas
- Roundabouts

Features

- Dedicated optics optimize beam control and maximize light output. Light distribution designed to take full advantage of the luminaire design system. Five different reflector positions allow precise control of beam direction.
- Flexible mounting capability, with special brackets for side entry or top mounting on mast arms with 34, 42-48 or 60 mm spigots, or for mast tops with 76 mm spigots.
- Choice of vandal- and UV-stabilised polycarbonate bowl or minimal-glare flat glass.
- Choice of lighting quality and running costs with HPL-N or HPL-COMFORT lamp up to 125W, SON or SON-T PLUS up to 150W, CDM-T 70 or 150W, QL 55W lamp, and PL-T4P 42W.

- Models with self-stopping ignitor and/or NEMA socket for photocell switching, and/or dimming gear for SON(-T) lamps available on request.
- High-strength, completely sealed construction resistant to weather and impact, for long service life and low repair and maintenance costs. Class I insulation (Class II for extra safety on request).
- Fast installation and easy maintenance from above by opening the housing with a single quick-release clip. Gear tray plugs in to allow fast replacement.

Materials and finish

Racket frame in non-corrosive diecast aluminium; canopy in grey glass-fibre reinforced UV-stabilized polyester or non-corrosive diecast aluminium; polycarbonate bowl or toughened flat glass; reflector in metalized high-purity aluminium.

Installation and mounting

Fix to any side entry or mast top spigot from 34 to 60 mm, or mast top spigot of 76 mm.

Accessories

Dual-purpose mounting brackets

lamp compartment



luminaire



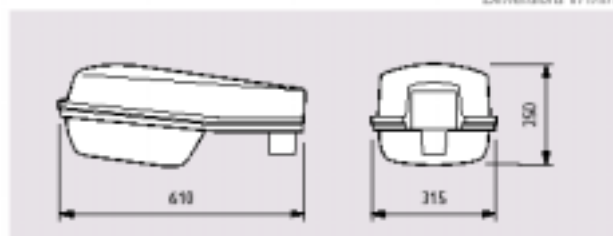
gear compartment

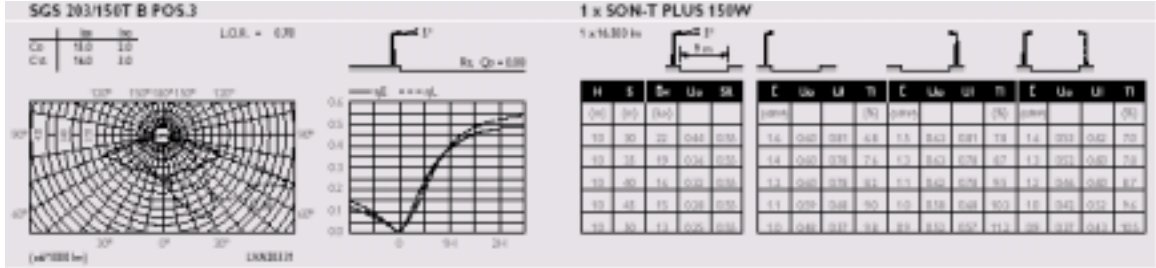


(on request)



Dimensions in mm





FURTHER INFORMATION: OTHERS LIGHTING CALCULUS SOFTWARE

Next list shows some lighting software used currently in the lighting graphical market.

1) Adeline

Adeline is an integrated lighting design computer tool developed by an international research team within the framework of the International Energy Agency (IEA) Solar Heating and Cooling Programme Task 12. It provides architects and engineers with accurate information about the behaviour and the performance of indoor lighting systems.

2) Communa-Lux

A PC-software tool for assisting in the operation of municipal street lighting systems. It considers operation, maintenance, and cost control.

3) The Home Energy Saver

The first interactive residential energy calculator on the web. Includes modules for all end uses, including lighting.

4) Lawrence design school

Private, on-linebased design school and tutorial.

5) Ledalite calculator

Ledalite's calculator uses the zonal cavity method to give a rough on-line estimate of fixtures needed and average illuminance.

6) Lightscape

The Lightscape Visualization System represents a new generation of computer graphics technology combining proprietary radiosity algorithms with a physically based lighting interface.

7) Radiance

Radiance is a suite of programs from the Lawrence Berkeley National Laboratory for the analysis and visualization of lighting in design. Input files specify the scene geometry, materials, luminaires, time, date and sky conditions (for daylight calculations).

Calculated values include spectral radiance (ie. luminance + color), irradiance (illuminance + color) and glare indices. Simulation results may be displayed as color images, numerical values and contour plots. The primary advantage of Radiance over simpler lighting calculation and rendering tools is that there are no limitations on the geometry or the materials that may be simulated.

8) Superlite 2.0

Superlite 2.0 is a powerful lighting analysis program from Lawrence Berkeley National Laboratory designed to accurately predict interior illuminance in complex building spaces due to daylight and electric lighting systems. SUPERLITE enables a user to model interior daylight levels for any sun and sky condition in spaces having windows, skylights or other standard fenestration systems.

9) Take-a-Break

A software application for calculating the profitability of turning off fluorescent lamps. From MOTIVA, Information Center for Energy Efficiency in Finland.

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