



Eladio Dieste Cristo Obrero Church in Atlántida, Uruguay

Lighting investigation for Computational Design

Basic Introduction

to lighting scenes in Rhino-Grasshopper
- HoneyBee

This short session will deal with a specific applied investigation case of predetermining lighting behavior of an artificial light source and a parametric reflecting geometry with the aim to investigate and analyze the behavior of the reflected light.

Honeybee connects Grasshopper3D to validated simulation engines such as EnergyPlus, Radiance, Daysim and OpenStudio for building energy, comfort, daylighting and lighting simulation.

Ladybug allows you to import and analyze standard weather data in Grasshopper; draw diagrams like Sun-path, wind-rose, radiation-rose, etc; customize the diagrams in several ways; run radiation analysis, shadow studies, and view analysis.

Learning goals for this short session include getting a basic familiarity with the setup of a scene and its analysis: Mesh verification, choosing and importing a light source, setting up our variables, virtual sensors, goals and automating design exploration.

By: **Kane Borg**
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Time: **13:00h - 15:30h**

Max. participants: --
Level: **Master** or **PhD**
Credits: --

(Basic knowledge of grasshopper3D)

Those who are familiar with grasshopper can follow the script build during the session by preinstalling software and plugins required for the example.

Topics

Grasshopper specific

Setting up a parametric model and its variables,
Setting up objectives and genetic algorithm to explore solutions.

HoneyBee specific

Verifying Mesh orientation and resolution,
Importing Light sources and editing them,
Assigning properties to in scene geometry,
Setting up a scene and its analysis settings,
Placing “virtual sensors” and setting objectives,
Exploring design variables.

Examples:

<link to gh file>

Software required to recreate example

Radiance
Source: <https://github.com/NREL/Radiance/releases>

Rhino 5 (Windows version) – Grasshopper

Plug-ins installed – LadyBug, HoneyBee.
Source: <http://www.food4rhino.com/app/ladybug-tools>
Installation instructions:
https://github.com/mostaphaRoudsari/ladybug/blob/master/resources/Installation_Instructions.md

Honeybee - Learning resources

Below are some resources and example reference to keep handy when using honeybee.

Plugin Page

Always a good resource for any plugin, FAQ's or highly viewed comments are a good resource for information relating to dealing with specific application.

<http://discourse.ladybug.tools/>

Examples

Examples for Shade & Glare analysis, HVAC loads, MicroClimate, indoor climate and much more practical applications of honeybee can be found in this example folder.

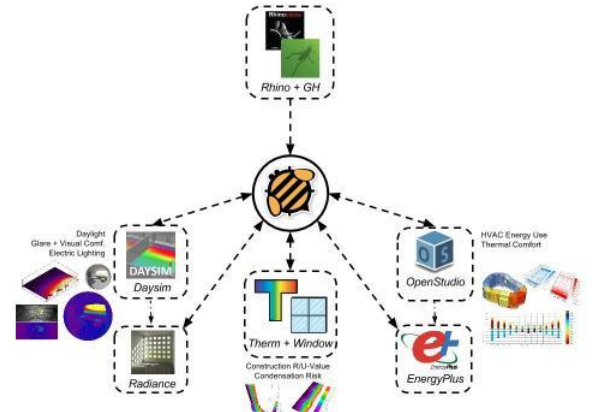
<https://hydrashare.github.io/hydra/index.html?keywords=HBExampleFiles>

Honeybee Primer

“Free automatically generated library from components of the plugin, here you can access the source code, descriptions, functions and assumptions of honeybee components.”

Download PDF an Web version
<https://www.gitbook.com/book/mostapharoudsari/honeybee-primer/details>

HoneyBee Workflow



- Rhino
 - Grasshopper
 - HoneyBee
 - DaySim
 - Radiance
 - EnergyPlus
 - OpenStudio

Other plugins instead of HoneyBee

Geco – uses Autodesk - Ecotect to run simulations which moved to Autodesk Revit (as of 2015) but it is still possible to utilize the legacy versions.

Diva – extends with Radiance and Energy Plus Commercial and Academic license available, equally good.

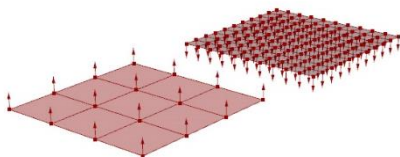
Heliotrope – Open license - Good for simple vector calculations. Heliotrope calculates solar position vectors at specific dates and times and provides a variety of components for manipulating those dates and times parametrically. Use it to create solar-aware design, to align geometry, position rendering lights, or analyze incident sun on structures.

Rhino Units

Due to the calculations in Honeybee assuming meters to be the document unit, the unit/tolerance settings of the document must reflect it. Also take 1 unit as a meter when designing as designing in mm leads to errors and indefinite loading times, since the program assumes your units as being meters.

1 UNIT = 1 METER
*in both rhino and grasshopper

Meshes: Orientation and Subdivision



Mesh directions dictate where the material external/internal face is located in the simulated model. In lighting models, the acting face should always have its orientation in the perpendicular direction of the face.

In single surface solids the normal of the mesh faces always points “out” however in multiple surface solids this should be always checked.

When simulating a reflecting surface or an analysis surfaces the design subdivision of the mesh we use in our analysis should be consider the following:

- The planarity of the surface,
- The computation time,
- The complexity of the light source (ERI info),

Vectors

(referenced from Wikipedia)

Euclidean vectors

In mathematics, physics, and engineering, a Euclidean vector (sometimes called a geometric or spatial vector, or—as here—simply a vector) is a geometric object that has **magnitude** (or length) and **direction**. Vectors can be added to other vectors according to vector algebra. A Euclidean vector is frequently represented by a line segment with a definite direction, or graphically as an arrow, connecting an initial point A with a terminal point B.

Vectors only contain information about **direction and magnitude**. In that sense, they don’t have a fixed position in space and can be freely “moved” around. Vectors in three dimensions require three coordinates (vector components) to be uniquely defined. Point vectors are vectors which point from the origin of the coordinate system to the point with same coordinates as the components of the point-vector. This makes point-vector’s and point’s notation interchangeable.

Basic properties of vectors

Equality - Two vectors are said to be equal if they have the same magnitude and direction. Equivalently they will be equal if their coordinates are equal.

Opposite, parallel, and antiparallel vectors - Two vectors are opposite if they have the same magnitude but opposite direction. Two vectors are parallel if they have the same direction but not necessarily the same magnitude, or antiparallel if they have opposite direction but not necessarily the same magnitude.

Length - Each vector has a length which can be calculated using **Euclidean norm** formula:

$$\|\mathbf{a}\| = \sqrt{a_1^2 + a_2^2 + a_3^2}$$

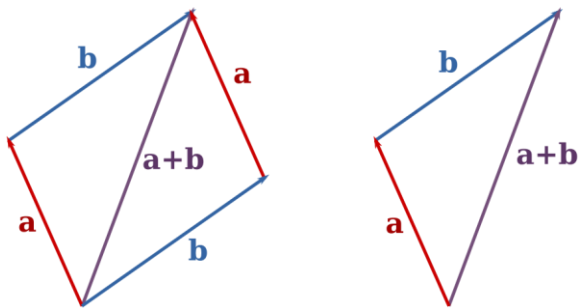
Euclidean norm works for vectors in any number of dimensions if we add squares of all components and calculate the square root of the sum. Calculating distances in higher-dimensional spaces has uses in modern data classification methods.

Unit vector - A unit vector is any vector with a **length of one**. Normally unit vectors are used simply to

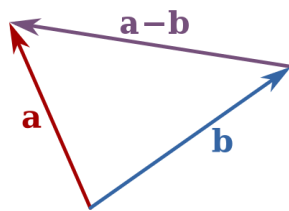
indicate direction. A vector of arbitrary length can be divided by its length to create a unit vector. This is known as **normalizing a vector**.

Zero vector - Vector with length zero. Unlike any other vector, it has an **arbitrary or indeterminate direction**, and cannot be normalized.

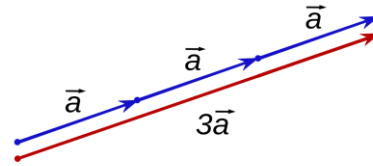
Vector addition - Vectors can be added to each other. Graphically, this is done by putting the start point of one on the end point of the other and drawing a vector from the start of the first to the end of the second vector. The result is always another **vector**.



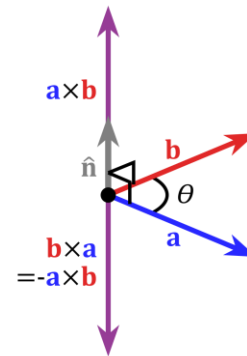
Vector subtraction - Vectors can be subtracted from each other. Graphically, one vector can be subtracted from the other by drawing a vector from the end of the second to the end of the first vector. The result is always another **vector**.



Scalar multiplication - Vector can be scaled in length by multiplying it with a skalar (a normal number, not another vector) in which case the direction stays the same. **If the scalar is negative, the vector will flip direction.** The result is always another **vector**.



Cross product - The cross product (also called the vector product or the **outer product**) of any two vectors is a **vector perpendicular to both of them** which completes a right-handed system. The right-handedness constraint is necessary because there exist two unit vectors that are perpendicular to any two vectors. Cross product can always be found unless two vectors have the same unit vectors or if one of them is a zero-vector. Otherwise, the result is always another **vector**.



Dot product - The dot product of two vectors (sometimes called the **inner product**, or, since its **result is a scalar**, the scalar product) can be defined as the sum of the products of the components of each vector as:

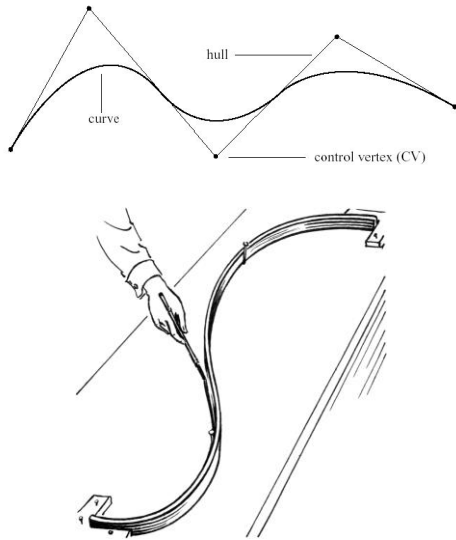
$$\mathbf{a} \cdot \mathbf{b} = a_1 b_1 + a_2 b_2 + a_3 b_3$$

Curve, surface and solid modeling
(referenced from Wikipedia)

NURBS

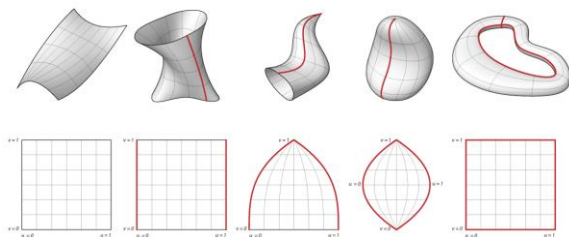
Non-uniform rational basis spline is a mathematical model commonly used in computer graphics for generating and **representing curves and surfaces**. It offers great flexibility and precision for handling both analytic (surfaces defined by common mathematical

formulae) and modeled shapes. NURBS are commonly used in computer-aided design (CAD), manufacturing (CAM), and engineering (CAE). NURBS tools are also found in various 3D modeling and animation software packages.



A spline curve and its physical counterpart

They can be efficiently handled by the computer programs and yet allow for easy human interaction. NURBS surfaces are functions of two parameters mapping to a **surface in three-dimensional space**. The shape of the surface is determined by control points. NURBS surfaces can represent, in a compact form, simple geometrical shapes. In general, editing NURBS curves and surfaces is highly intuitive and predictable. Control points are always either connected directly to the curve/surface, or act as if they were connected by a rubber band.



Examples of NURBS surfaces and their seam lines

Before computers, designs were drawn by hand on paper with various drafting tools. Rulers were used for

straight lines, compasses for circles, and protractors for angles. But many shapes, such as the **freeform curve of a ship's bow**, could not be drawn with these tools. Although such curves could be drawn freehand at the drafting board, shipbuilders often needed a life-size version which could not be done by hand. Such large drawings were done with the help of flexible strips of wood, called **splines**. The splines were held in place at a number of predetermined points, called "**ducks**"; between the ducks, the elasticity of the spline material caused the strip to take the shape that minimized the energy of bending, thus creating the **smoothest possible shape that fit the constraints**. The shape could be tweaked by moving the ducks.

In 1946, mathematicians started studying the spline shape, and derived the piecewise **polynomial formula** known as the spline curve or **spline function**. I. J. Schoenberg gave the spline function its name after its resemblance to the mechanical spline used by draftsmen. As computers were introduced into the design process, the physical properties of such splines were investigated so that they could be modelled with mathematical precision and reproduced where needed. Pioneering work was done in France by **Renault engineer Pierre Bézier**, and **Citroën's physicist and mathematician Paul de Casteljaou**. They worked nearly parallel to each other, but because Bézier published the results of his work, **Bézier curves** were named after him, while de Casteljaou's name is only associated with related algorithms.

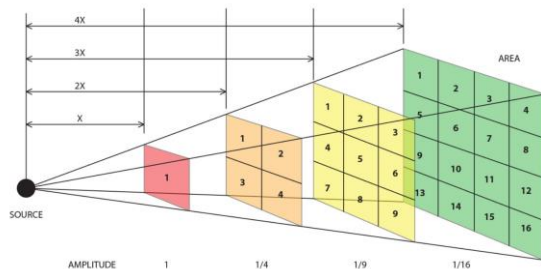
BREP

Boundary representation is a method for representing shapes using the limits. A solid is represented as a **collection of connected surface elements**, the boundary between solid and non-solid. Boundary representation of models are composed of two parts: topology and geometry (surfaces, curves and points). The main topological items are: **faces, edges and vertices**. A face is a bounded portion of a surface; an edge is a bounded piece of a curve and a vertex lies at a point. Compared to the constructive solid geometry (CSG) representation, which uses only primitive objects and Boolean operations to combine them, boundary representation is more flexible and has a much richer operation set. In addition to the **Boolean operations**, B-rep has extrusion (or sweeping), chamfer, blending, drafting, shelling,

tweaking and other operations which make use of these.

Inverse-square law

Any **physical law** stating that a specified physical quantity or intensity is **inversely proportional to the square of the distance** from the source of that physical quantity.



The fundamental cause for the inverse-square law can be understood as geometric dilution corresponding to point-source radiation into three-dimensional space.

The inverse-square law generally applies when some force, energy, or other conserved quantity is **evenly radiated outward from a point source** in three-dimensional space. Since the surface area of a sphere (which is $4\pi r^2$) is proportional to the square of the radius, as the emitted radiation gets farther from the source, it is spread out over an area that is increasing in proportion to the square of the distance from the source. Hence, the intensity of radiation passing through any unit area (directly facing the point source) is inversely proportional to the square of the distance from the point source. **Gauss' law** is similarly applicable, and can be used with any physical quantity that acts in accord to the inverse-square relationship.

Light

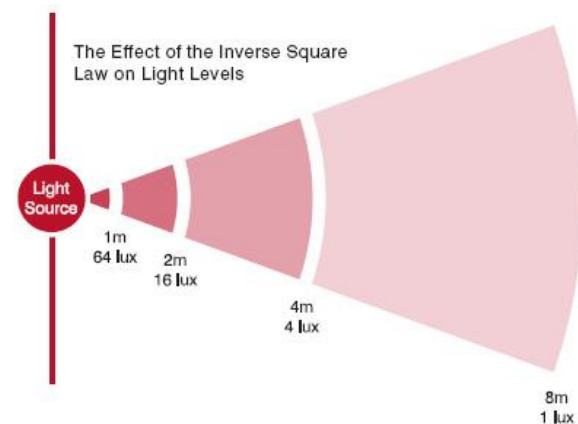
The intensity (or illuminance or irradiance) of light or other linear waves radiating from a point source (energy per unit of area perpendicular to the source) is inversely proportional to the square of the distance from the source. An object (of the same size) twice as far away, receives only one-quarter the energy (in the same time period).

Luminous flux (lumen)

The lumen (symbol: lm) is the SI derived unit of luminous flux, a measure of the total quantity of visible light emitted by a source. Luminous flux differs from power (radiant flux) in that radiant flux includes all electromagnetic waves emitted, while luminous flux is weighted according to a model (a "luminosity function") of the human eye's sensitivity to various wavelengths. Lumens are related to lux in that one lux is one lumen per square meter.

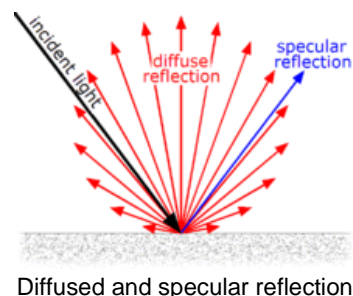
Wikipedia :: "Lumen"

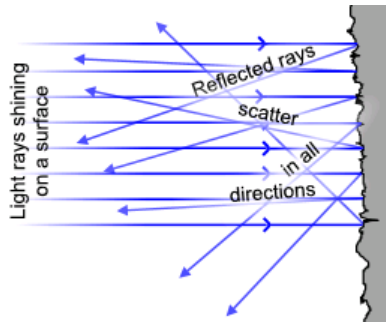
Lux



The lux (symbol: lx) is the SI derived unit of illuminance and luminous emittance, measuring luminous flux per unit area. It is equal to one lumen per square meter. In photometry, this is used as a measure of the intensity, as perceived by the human eye, of light that hits or passes through a surface. – Wikipedia :: "Lux"

Diffused Reflection

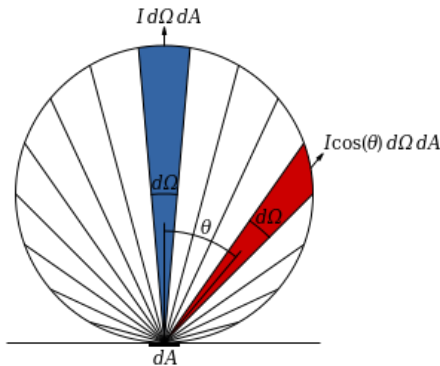




Diffuse reflection from irregular surface

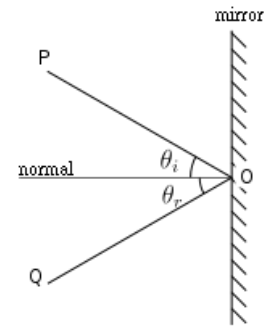
Diffuse reflection is the reflection of light or other waves or particles from a surface such that a ray incident on the surface is scattered at many angles rather than at just one angle as in the case of specular reflection. An ideal diffuse reflecting surface is said to exhibit Lambertian reflection, meaning that there is equal luminance when viewed from all directions lying in the half-space adjacent to the surface. – Source: Wikipedia

Lamberts cosine law

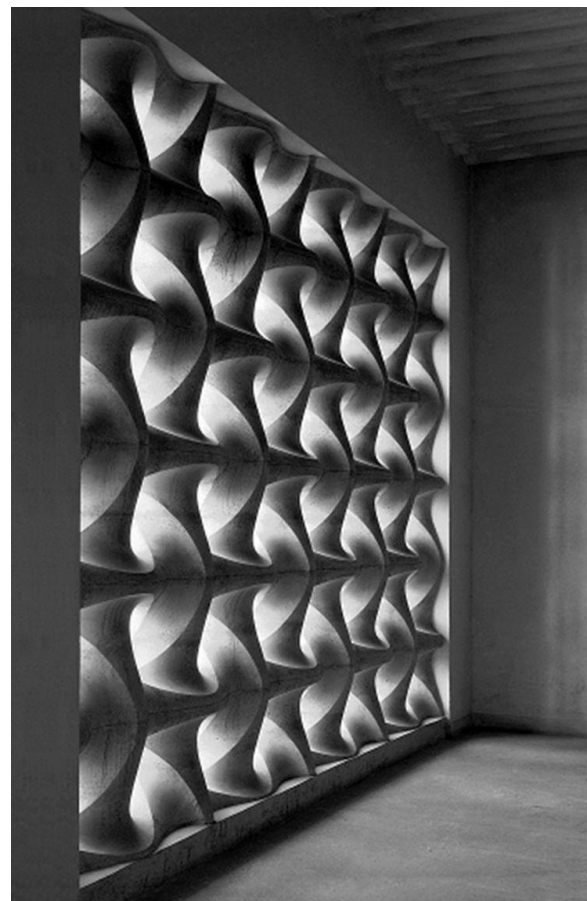


“In optics, Lambert’s cosine law says that the radiant intensity or luminous intensity observed from an ideal diffusely reflecting surface or ideal diffuse radiator is directly proportional to the cosine of the angle θ between the direction of the incident light and the surface normal. The law is also known as the cosine emission law or Lambert’s emission law.” – Source: Wikipedia

Specular Reflection



“also known as regular reflection, is the mirror-like reflection of waves, such as light, from a surface. In this process, each incident ray is reflected, with the reflected ray having the same angle to the surface normal as the incident ray. The result is that an image reflected by the surface is reproduced in mirror-like (specular) fashion” – Source: Wikipedia

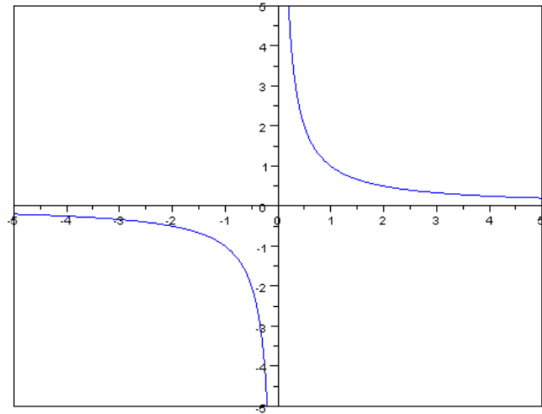


Erwin Hauer – light-diffusing wall design Liesing, Vienna, Austria, 1951

Concentrated Reflection

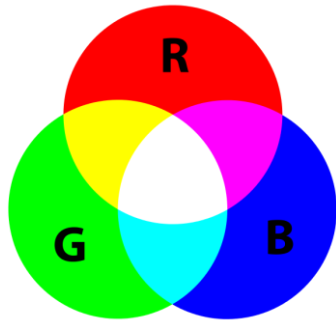


Rafael Viñoly – “Death beam melting cars”, Walkie-Talkie, 20 Fenchurch Street, London. Source – bbc.com



Inverse proportionality diagram. Variable y is directly proportional to the variable x.

RGB color model



Additive color model in which **red, green and blue light** are added together in various ways to reproduce a broad array of colors. The main purpose of the RGB color model is for the sensing, representation and display of images in **electronic systems**, such as televisions and computers, though it has also been used in conventional photography.

Color dependent absorption

In the same way the red and blue light is absorbed by chlorophyll to make a leaf appear green, various pigments reflect, and absorb different proportions of the incident light. It is also important to observe that reflected light from a leaf is primarily green so any secondary bounces of the reflected light has disproportionately less blue and red wavelengths, effectively washing indirectly illuminated surfaces in green or [red-blue deficient sunlight].

Artificial light

IES files



“... the lighting objects are associated with a photometry via IES files. The photometry of a light fixture describes the way it distributes its light into space. Once this process is completed, the illuminance and luminance produced by each fixture in the space can be calculated. The output is typically a diagram indicating these by means of colors or numbers...”

Source - Wikipedia

```

Luminaire Catalog Number: 1
Luminaire Description: L1 small
Lamp Catalog Number: Fiber nr 1
Lamp Description: Fiber nr 1

Luminaire Manufacturer: Parans
IES File Format Type: IESNA:LM-63-2002
Photometry Type: C

Number of Lamps: 1
Lumens per lamp: 1000.0
Units Type: meters
Luminous Dimensions (width,length,height): 0.4,0.4,0.015.
(The luminous opening is rectangular with luminous sides.)

Number of Vertical Angles:37
Vertical Angle limits:0.0,180.0

Number of Horizontal Angles: 13
Horizontal Angle limits: 0.0,360.0
    
```

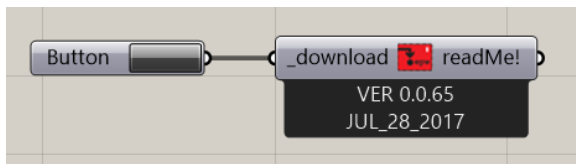
Info of IES file as extracted by the HoneyBee Lum Component

Example Distributor IES files available for download:
<http://www.eclipselightinginc.com/pages/download/photometric-ies-files.php>

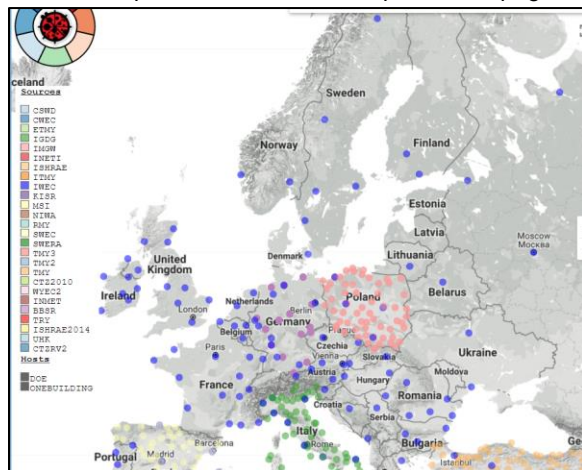
Sunlight

EPW files

Ladybug comes with a download link for getting the required epw files.

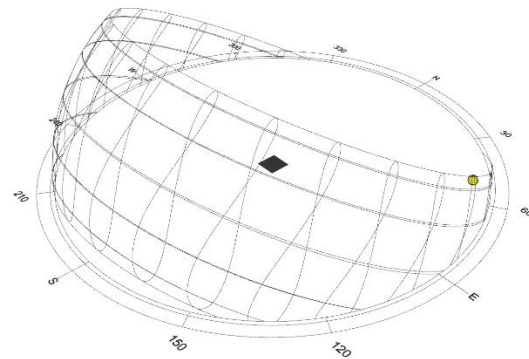
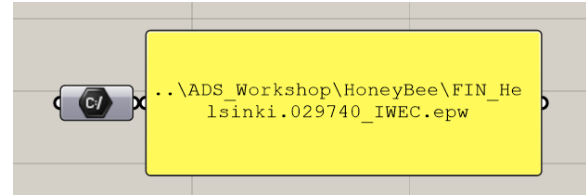


When the input is set to true it will open a web page:

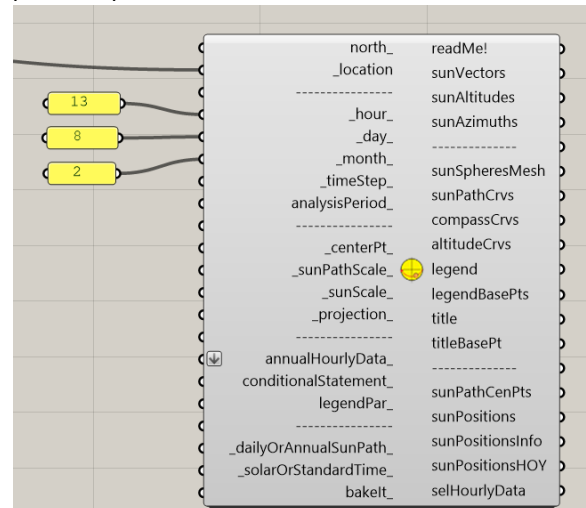


Here you can select which epw to download by geo location.

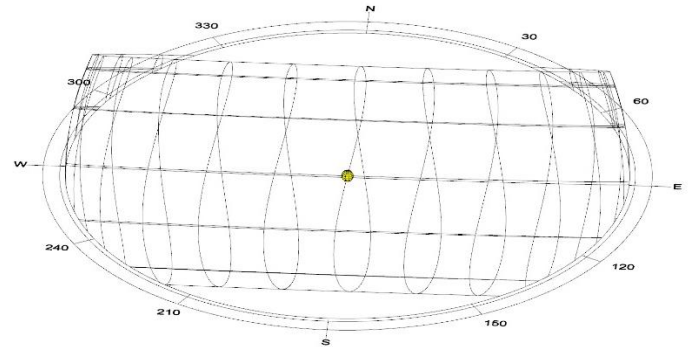
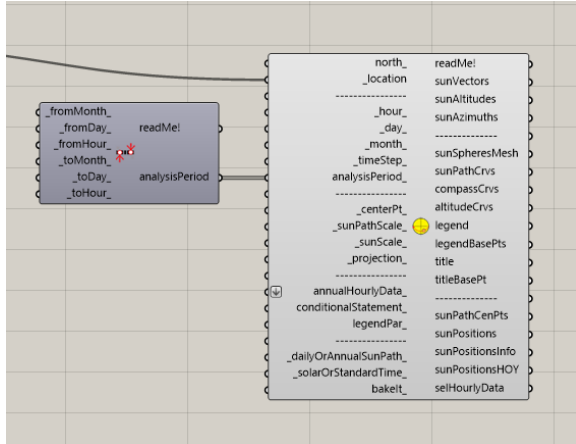
Once saved, you can unzip the file and link the epw by referencing its path:



By default, the North point will be set to the world Y positive axis, but you can modify this by providing a vector for it. You can extract location coordinates equal to the weather file coordinates with the location component. You can investigate singular instances in time by using the hour/day/month entries in the sun path component,



or periods of time using the analysis period component and choosing a time step (default = 1/hr).



12:00 day = 21 month = 9

Vector generation

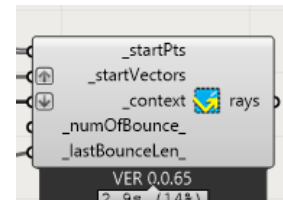
The forward raytracing component is good for tracing the path of tracing the bounce path of rays of light from source such as the sun vectors paths and uses the context to map the reflection path. The resolution of the context mesh is critical for the accuracy of the bounce to be realistic. For detailed investigation, use surfaces or finely subdivided meshes.

Direct Radiation, Diffuse Radiation, Total Radiation.

"Direct radiation" is also sometimes called "beam radiation" or "direct beam radiation". It is used to describe solar radiation traveling on a straight line from the sun down to the surface of the earth.

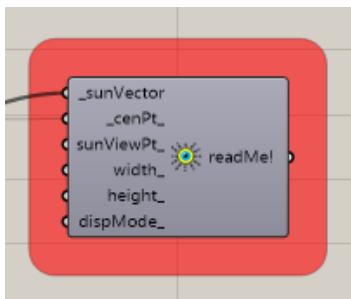
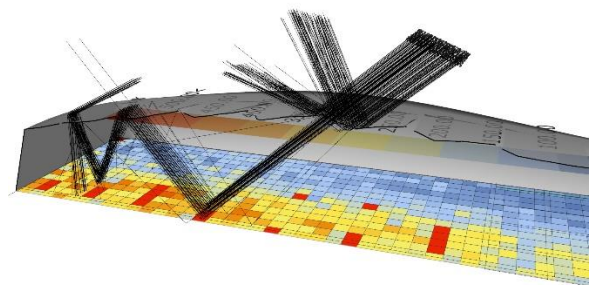
"Diffuse radiation", on the other hand, describes the sunlight that has been scattered by molecules and particles in the atmosphere but that has still made it down to the surface of the earth.

"Total radiation", is the vectoral summation of both direct and diffuse radiation.



View from sun

To create a viewport of rhino aligned with a particular time in day you can use the View from sun component.



Lux/Luminance Grid Analysis

To quantitatively measure how much lux are seen by a particular area you can set an analysis grid to perform reverse raytracing for that area.

