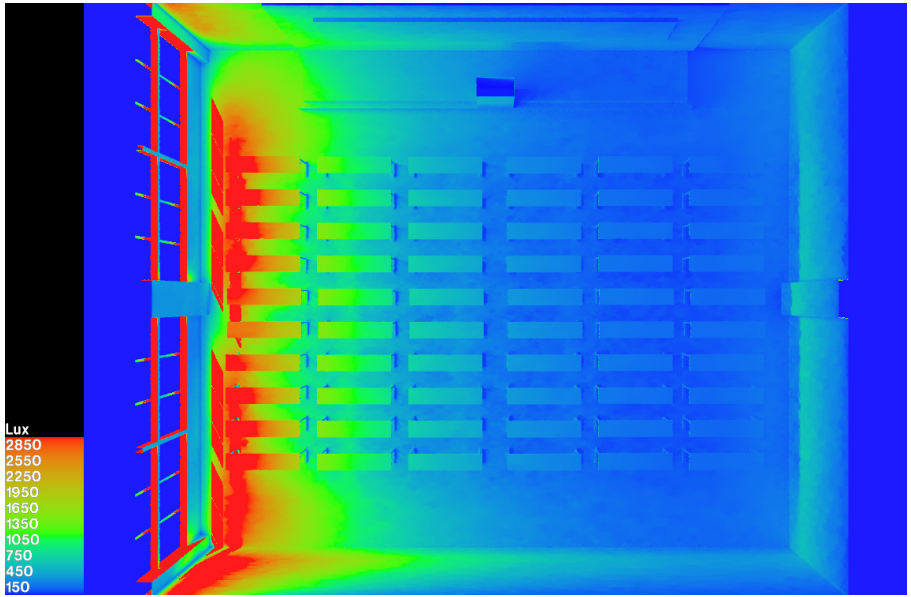
An Expression of Three-Dimensional Distribution of Light in Architecture with Photon Flows

29.08.2016 Radiance Workshop in Padua

Nozomu Yoshizawa
Satoshi Mori
Tokyo University of Science

Introduction

- Lighting distribution is usually depicted in two-dimensional expression like horizontal illuminance distribution.

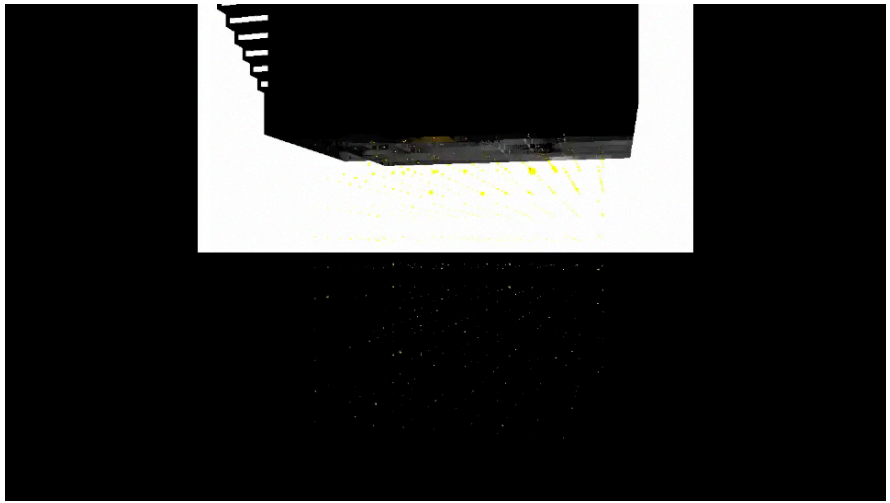


Introduction

- Some architects or lighting designers sometimes express their desire to get useful tools to visualize the light flow when they build a rough sketch of architectural/lighting design.

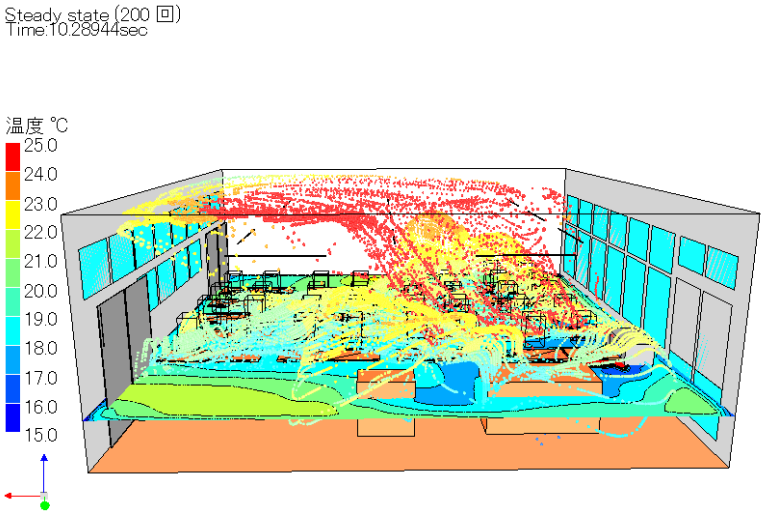
Introduction

- Scalar illuminance/illuminance vectors are superior way to express lighting in three dimensions, but its visual expression using spheres and arrows cannot always be intuitively recognized.



Introduction

- In air flow/thermal environment simulation, air flow is sometimes depicted by the small spheres in the 3D perspectives.



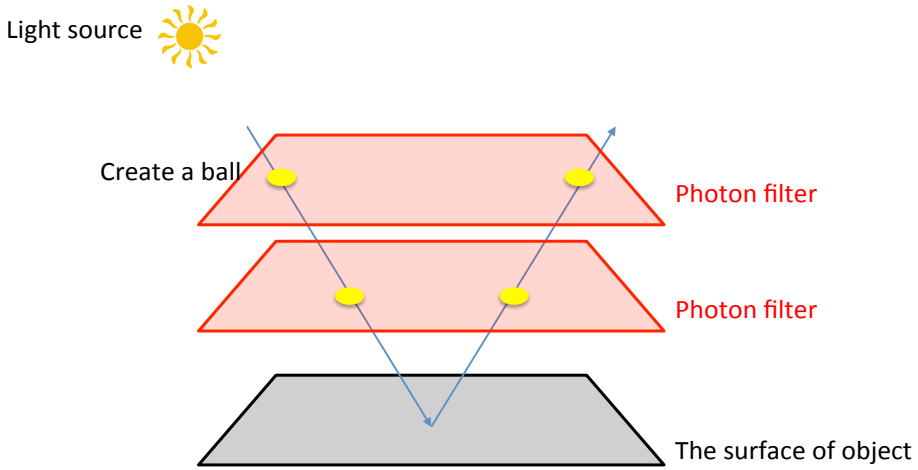
Calculated by Flow Designer

Purposes

- Couldn’t we also express light flow in 3D perspectives in the process of BIM?
- Photon mapping algorithm calculates virtual photon flows, so what if we catch them on the virtual surfaces?

Photon Filiters

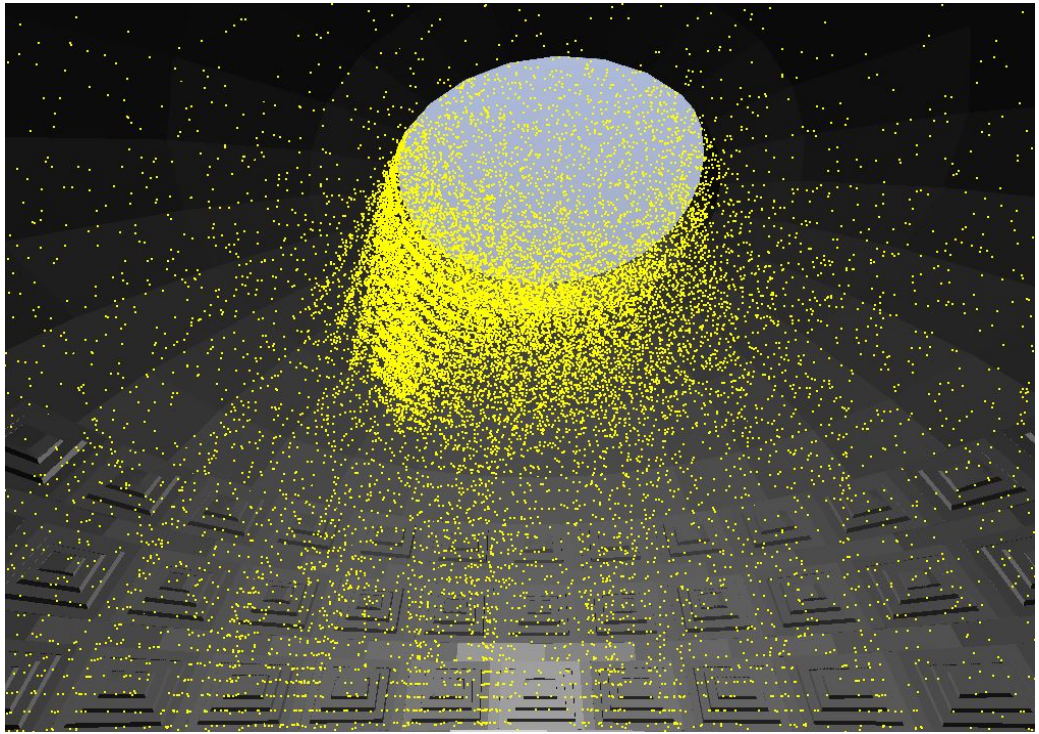
- We put some invisible planes(filters) made of special material in the space, and when a photon hits this material, its position information will be recorded in text files, then the photon will pass this material and move on in the same direction without losing the energy.



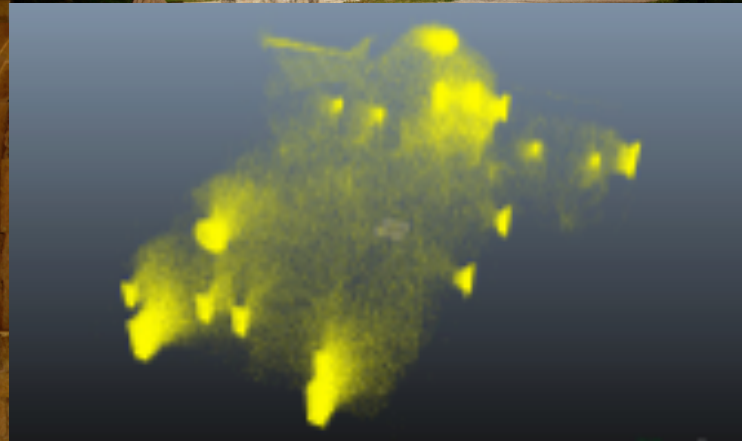
Photon Filiters

- A visible sphere will be created at the collided points. Putting the filter layers in parallel makes it possible to visualize photon flow, that is, the flow of light within a space.
- In the beginning, 3DCG software Maya with rendering plug-in Mental Ray was used. The new material_“Photon Filter” was made by Maya Programming.

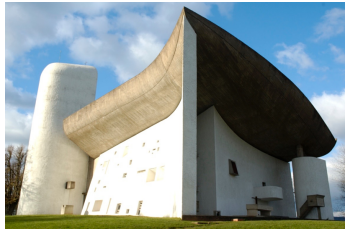
Pantheon

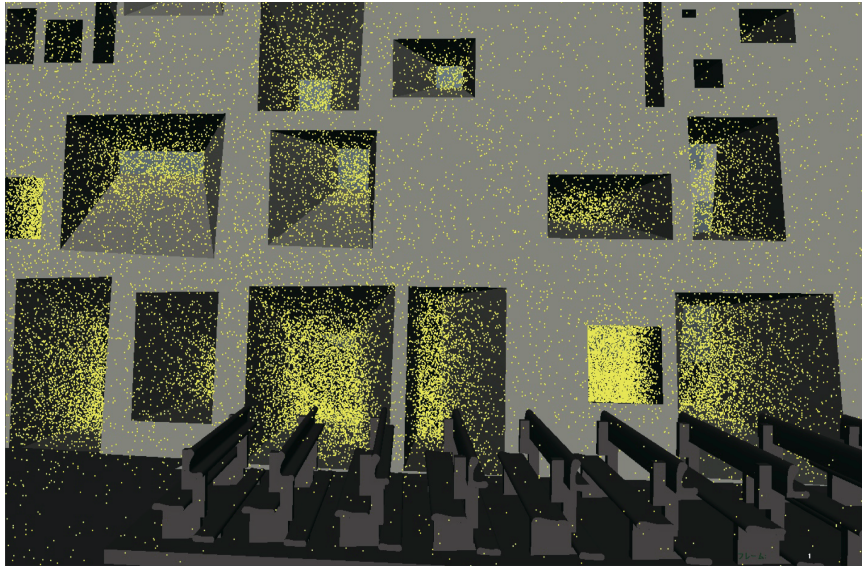


Le Thoronet Abbey



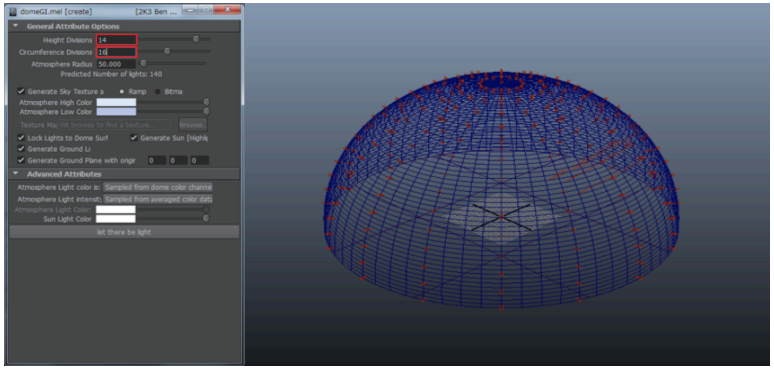
La chapelle Notre-Dame du Haut at Ronchamp





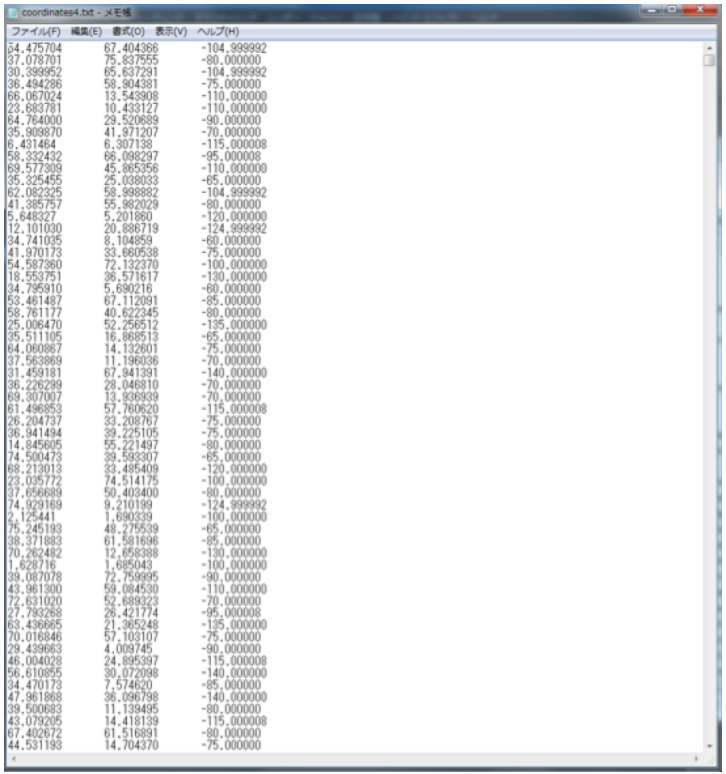
Maya with Mental Ray

- Sun: MentalRay_PhysicalSun
- Sky: domeGI.mel_Virtual Hemisphere Dome
  - Sky is divided to 224 pieces, and luminance is allocated to each piece, in reference to CIE standard skies , and the number of photons emitted from each piece was decided.

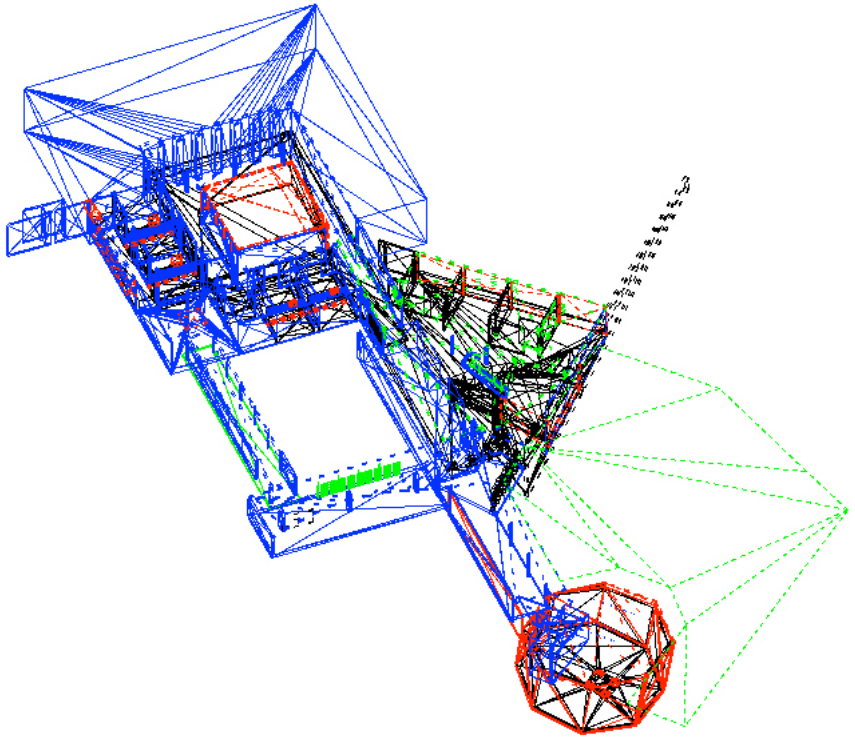


Maya with Mental Ray

- Collided points' coordinates are outputted to the text file.
- This data can be imported to Rhinoceros, or other modelling programs.

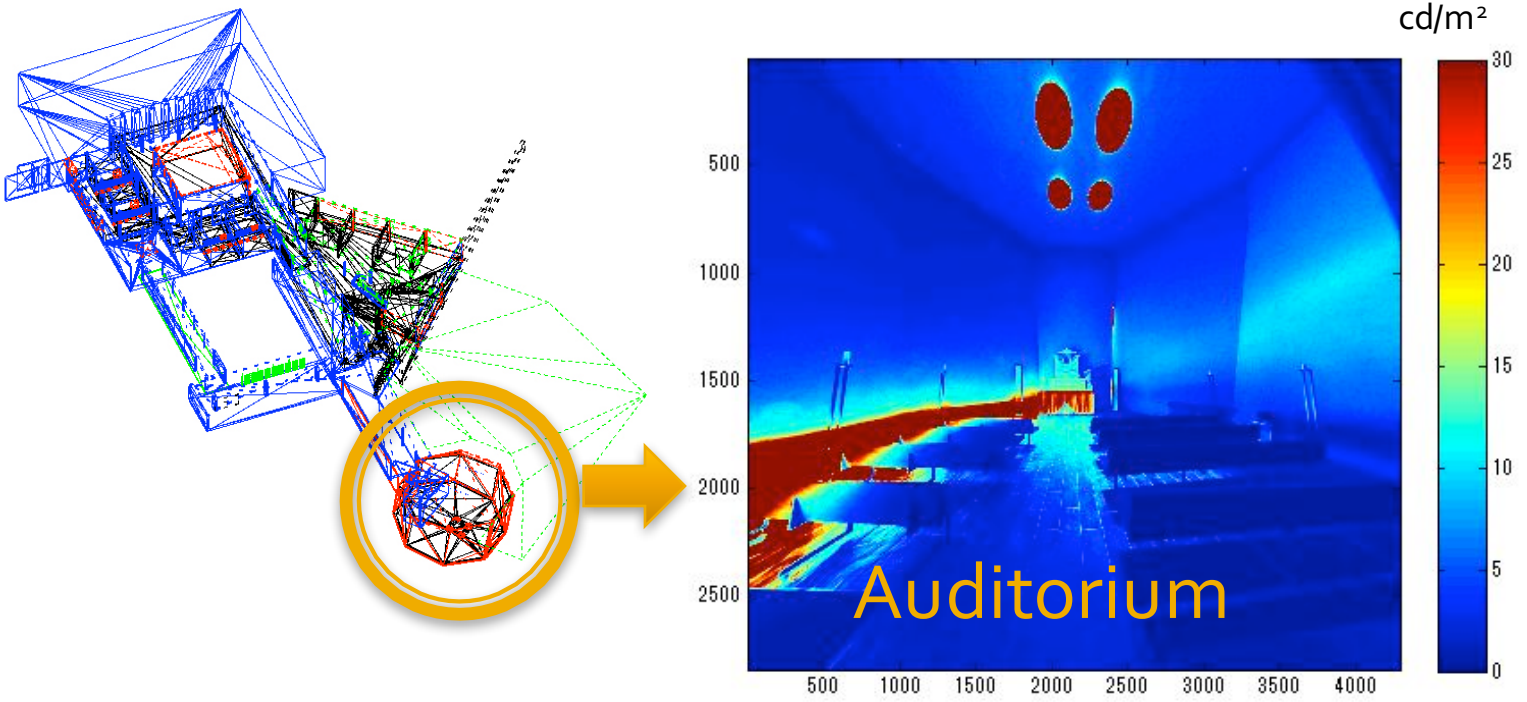


Kaze-no-oka Crematorium



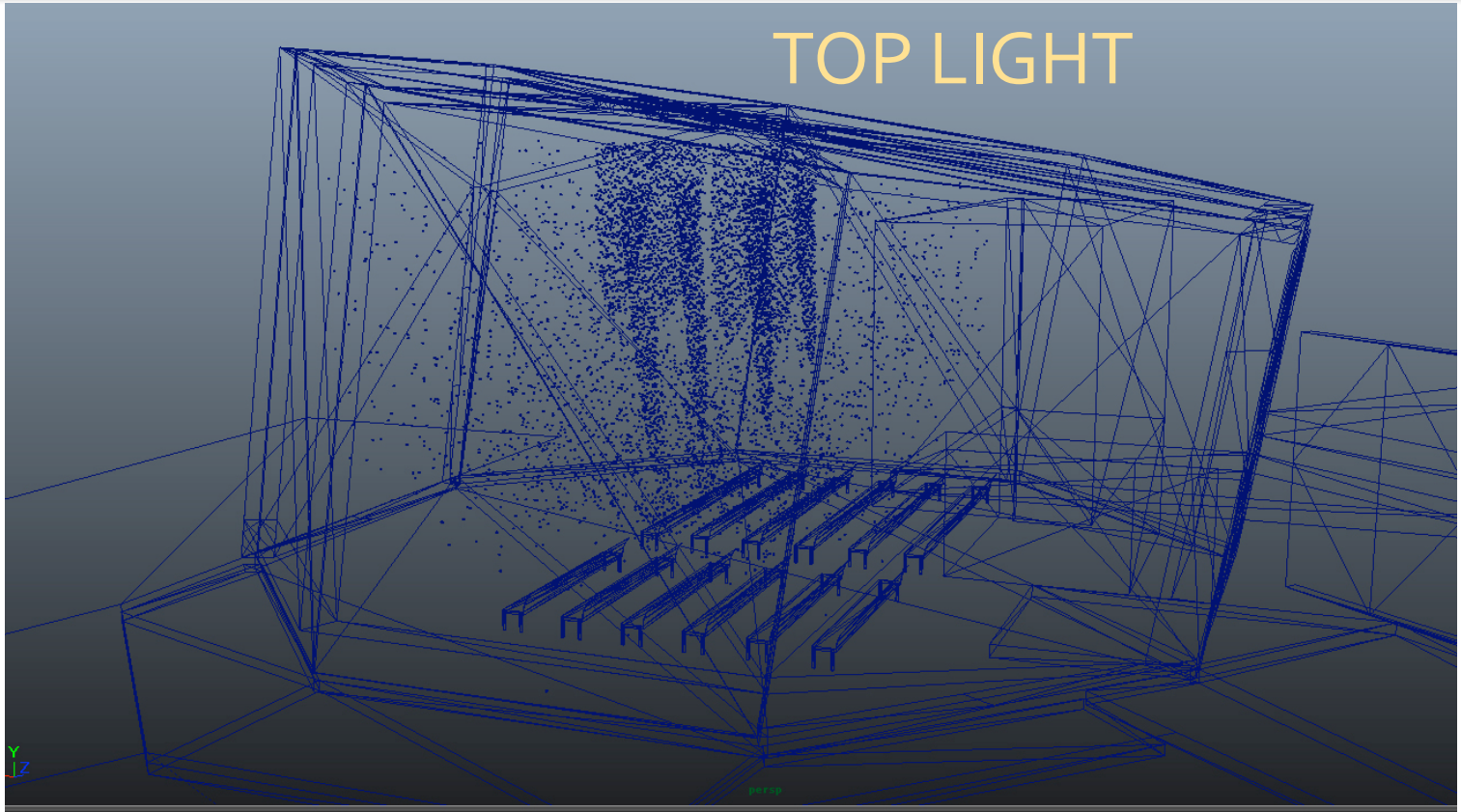
Designed by Humihiko Maki in 1997

Kaze-no-oka Crematorium

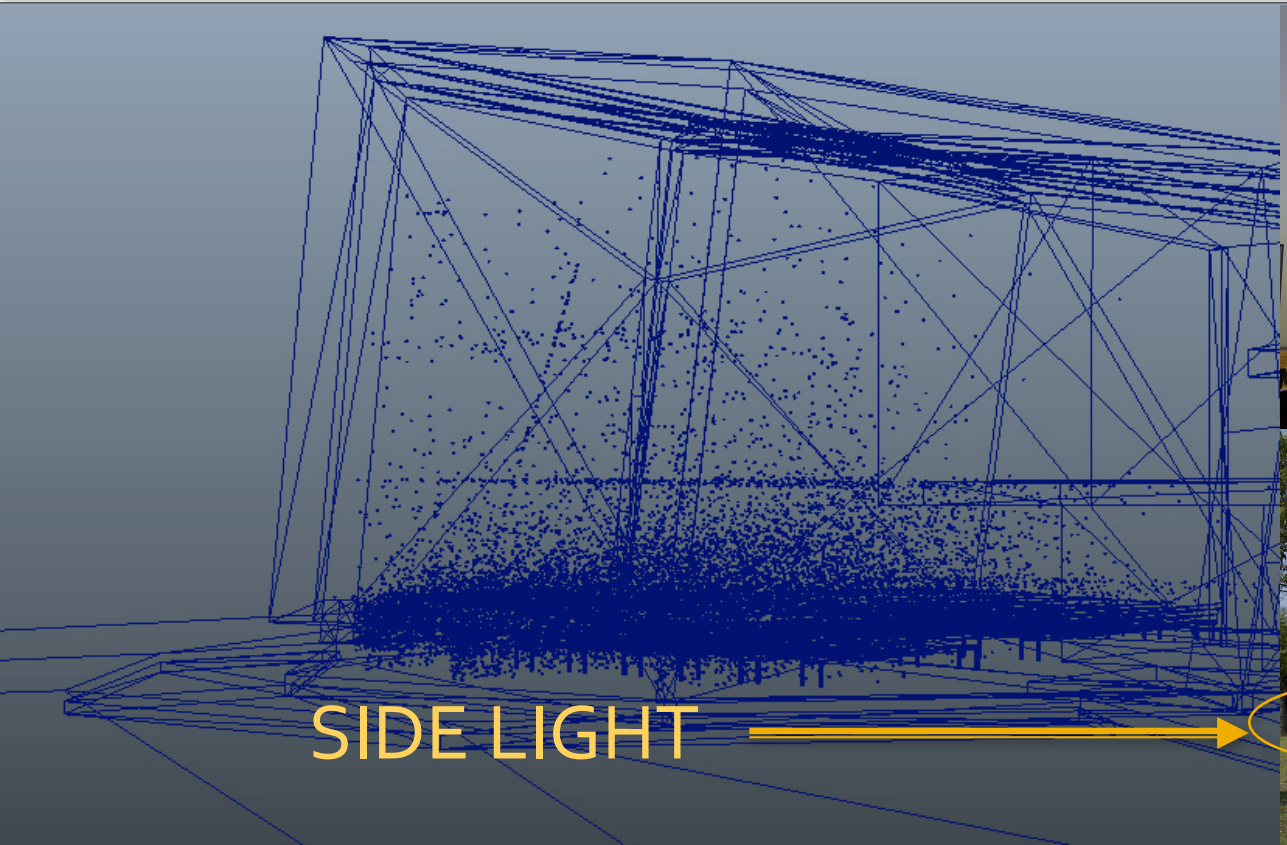


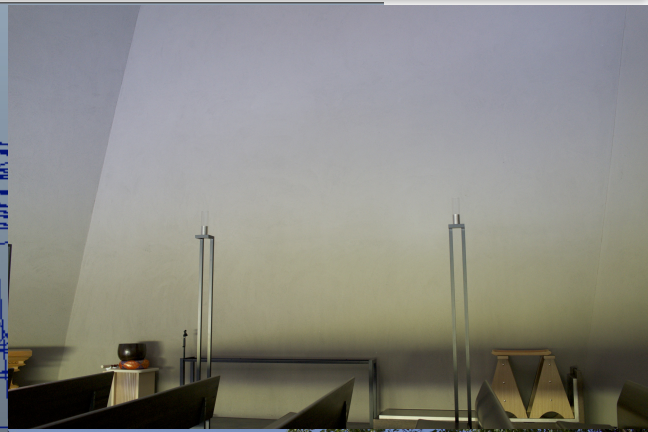
Its auditorium has two openings: top lights and lower side light

Kaze-no-oka Crematorium

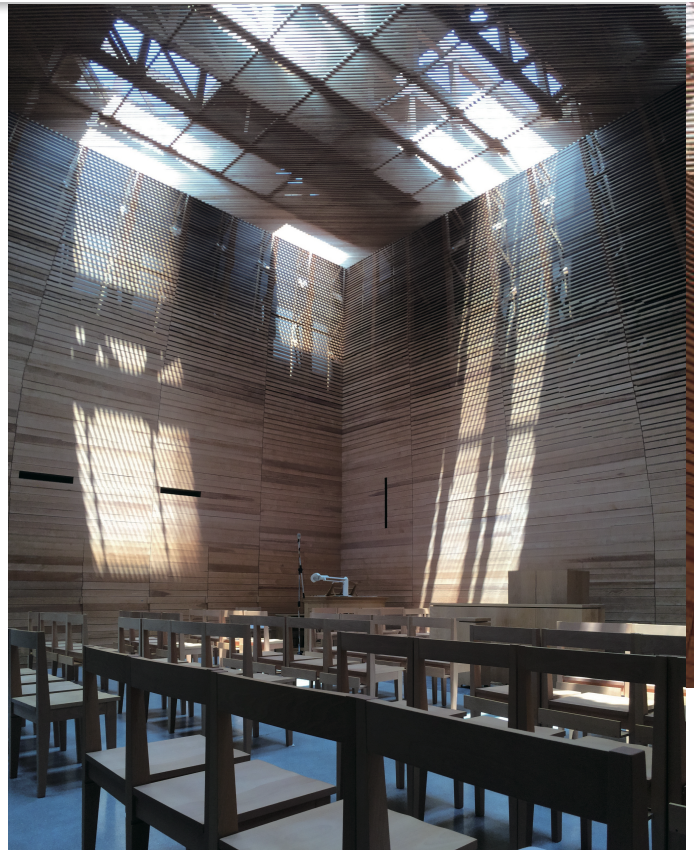


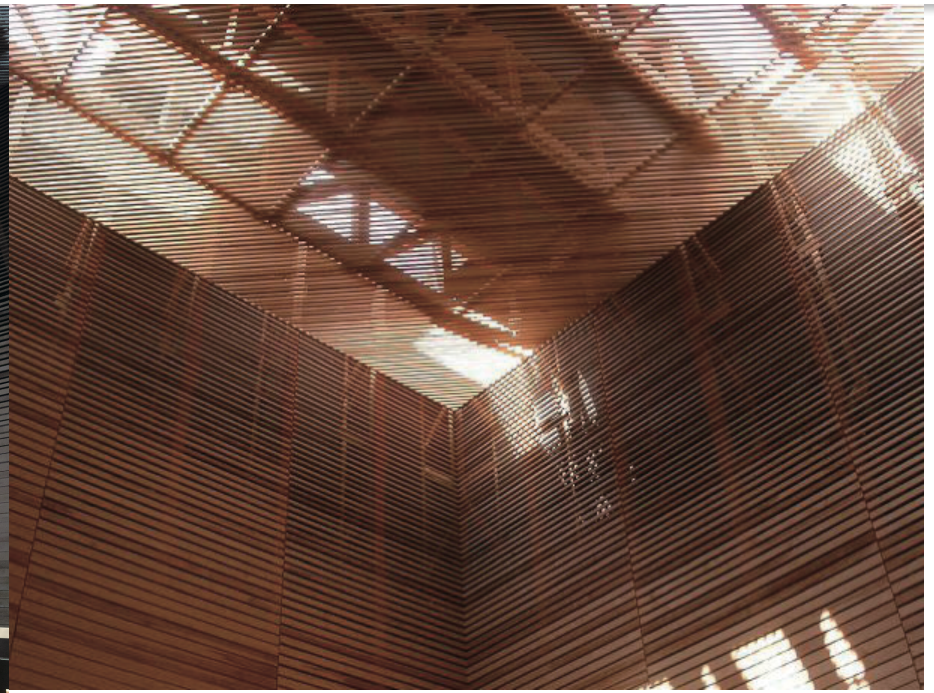
Kaze-no-oka Crematorium





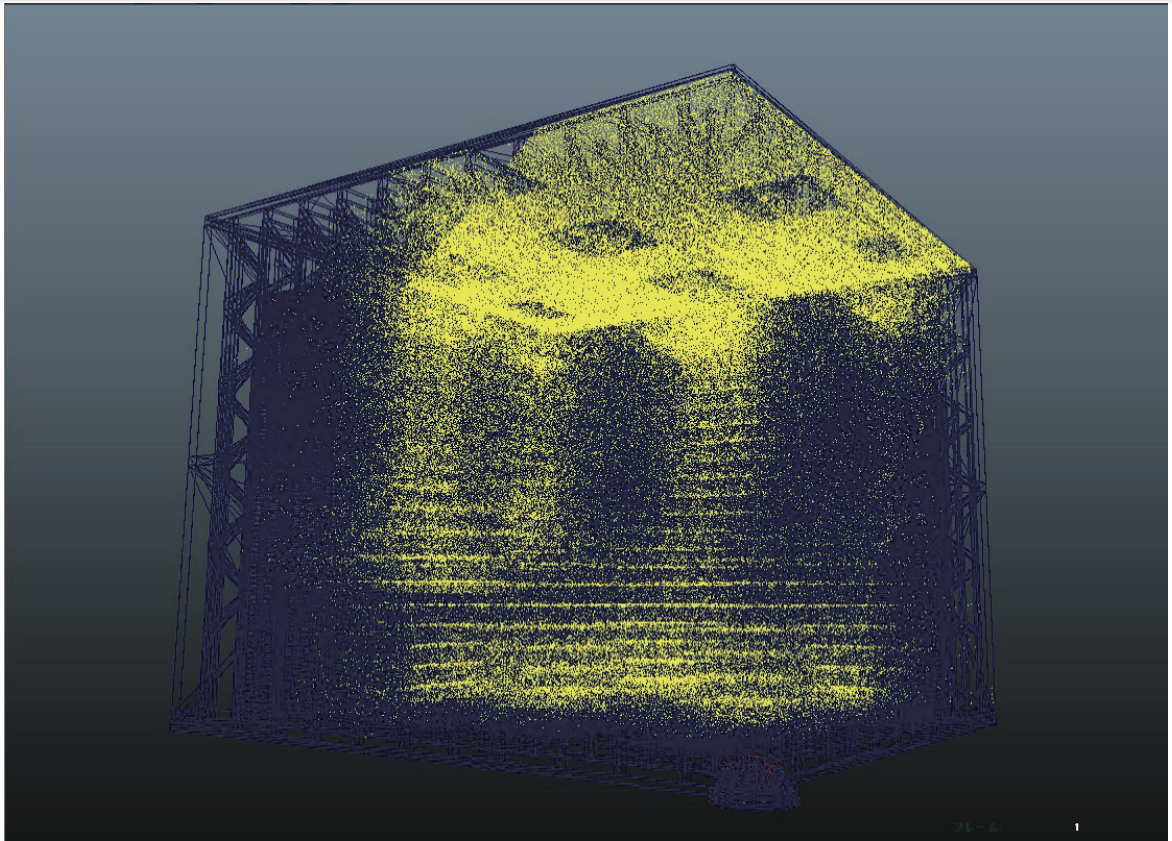
Sunpu Church





Designed by TAIEA NISHIZAWA in 2008

Sunpu Church

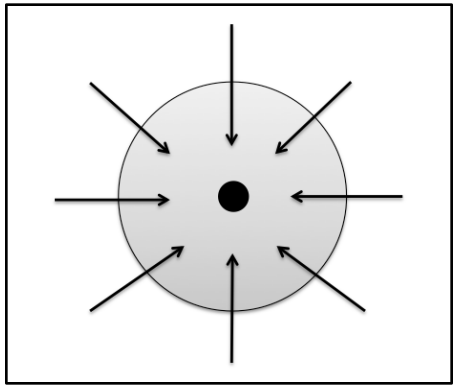


What exactly can be inferred from Photon Flow?

- There is a risk of misleading designers and architects into a wrong interpretation of light environment, because, strictly speaking, we could not infer the appearances of the buildings from the photon flow.
- Luminance distribution is necessary for understanding correct appearances.

Scalar illuminance

- Theoretically density of photons - number per unit volume - will equate with scalar illuminance?



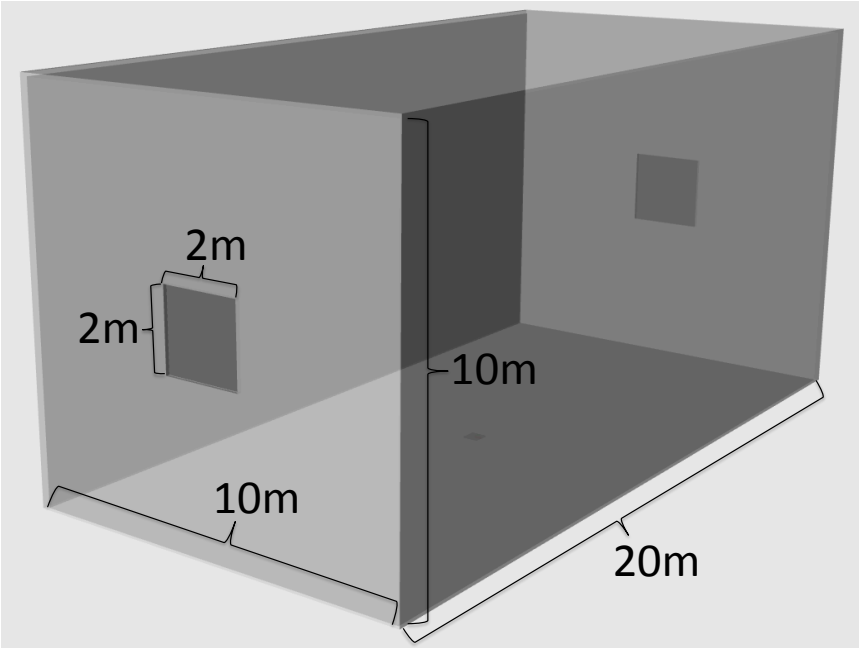
Scalar Illuminance
=the mean illuminance over the surface of a sphere

Scalar illuminance and Density of Photons

- We verified this assumption by calculating scalar illuminance and the density of photons in a simple rectangular space using the latest Radiance.

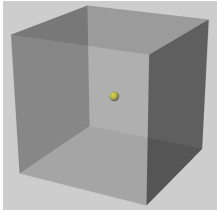
Scalar illuminance and Density of Photons

- A simple rectangular box 10m wide, 20m long and 10m in height
- Two openings of 2m square

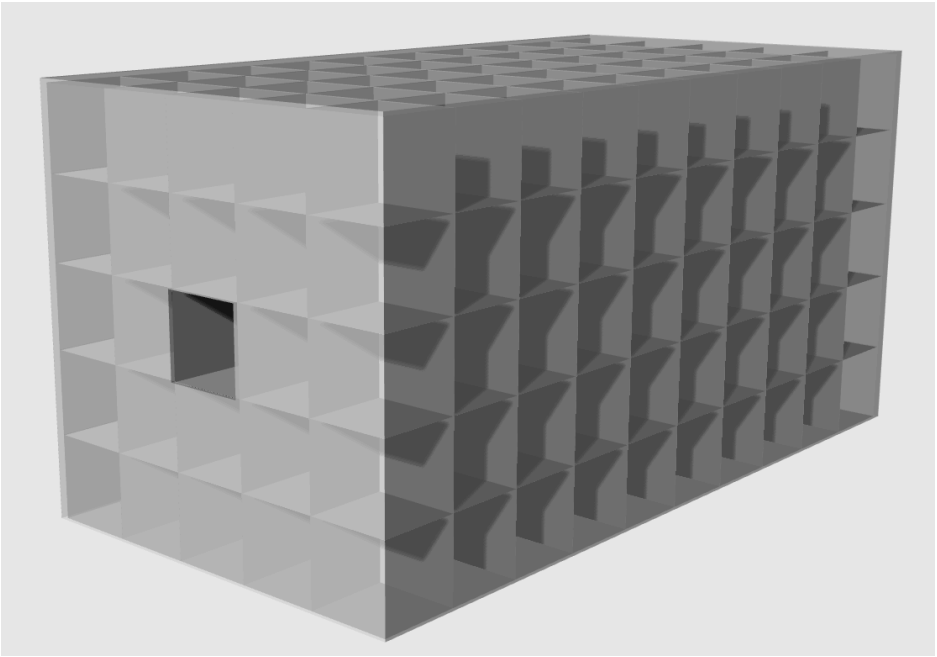


Scalar illuminance and Density of Photons

- Divided into 250 cubes of 2m*2m*2m



The scalar illuminance of the center of each cube was calculated and the number of photons in each cube was counted.



Scalar illuminance and Density of Photons

① $E_{(x)} = E_{(x+)} - E_{(x-)}$ Vector component of each coordinate axis

② $|E| = \sqrt{\left(E_{(x)}^2 + E_{(y)}^2 + E_{(z)}^2\right)}$ Composition of vectors

③ $\sim E_{(x)} = \frac{E_{(x+)} + E_{(x-)} - |E_{(x)}|}{2}$ Symmetric component of each coordinate axis

④ $\sim E = \frac{\sim E_{(x)} + \sim E_{(y)} + \sim E_{(z)}}{3}$ The average of symmetric components

⑤ $E_{sr} = \sim E + \frac{|E|}{4}$ Scalar Illuminance : ②+④

※ E_{sr}: Scalar Illuminance

In reference to Lighting by Design by Dr.Cuttle

Scalar illuminance and Density of Photons

- Photon Filter in Radiance
  …in a tentative way!

```
void trans photonfilter
0
0
7   1   1   1   0   0   0.99999   1
```

specular transmittance = (1 – spec) * colour * trans * tspec
= (1 – 0) * 1 * 0.99999 * 1
= 0.99999

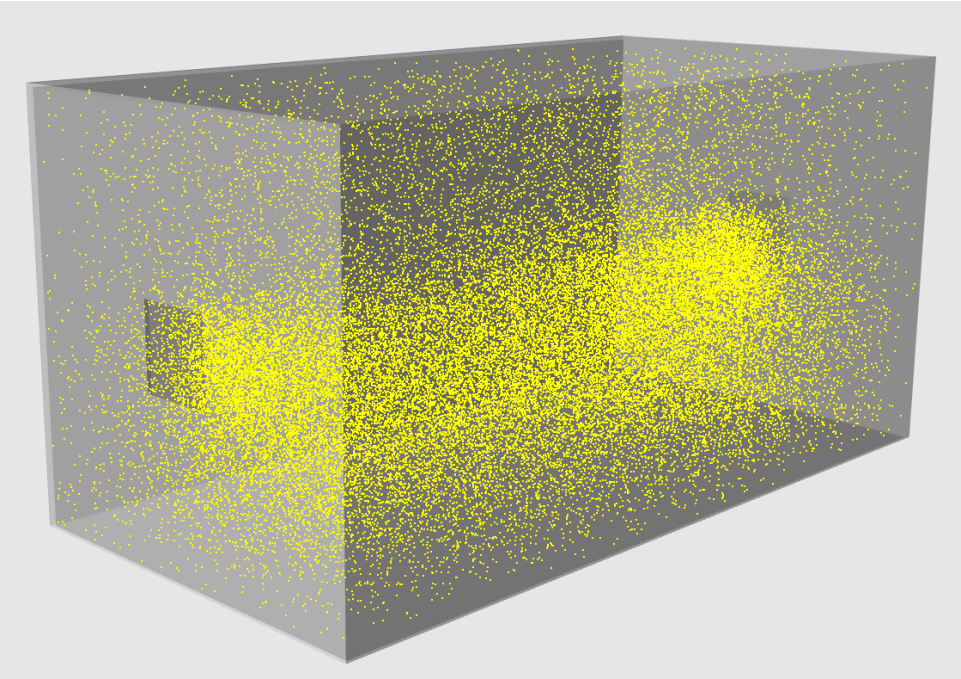
Scalar illuminance and Density of Photons

- mkpmap -apg try.pmap 30000 try.oct
- pmapdump -n 30000 try.pmap > photontry.rad
- Extract the xyz data of each collided points

Visualize photon flows in Rhinoceros

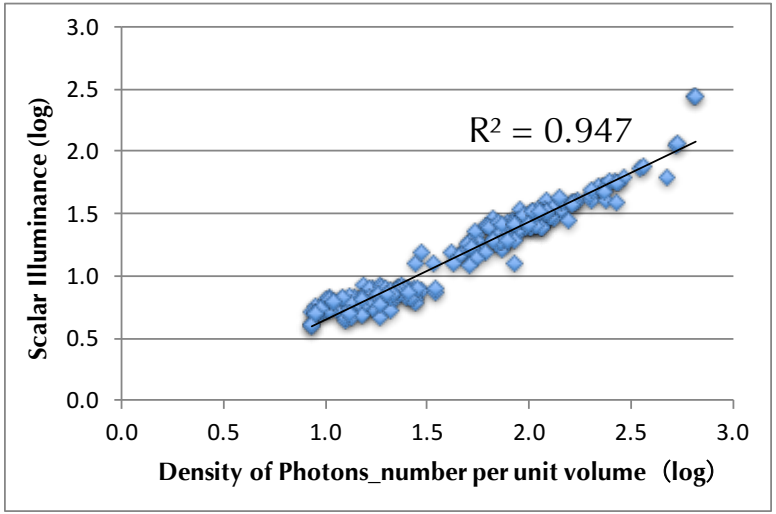
Scalar illuminance and Density of Photons

Visualize photon flows in Rhinoceros



Scalar illuminance and Density of Photons

The correlation coefficient indicates a strong positive correlation between them.



Absolute values of light intensity should be reflected on photon densities, though…in future works…

NATIONAL MUSEUM OF WESTERN ARTS IN TOKYO

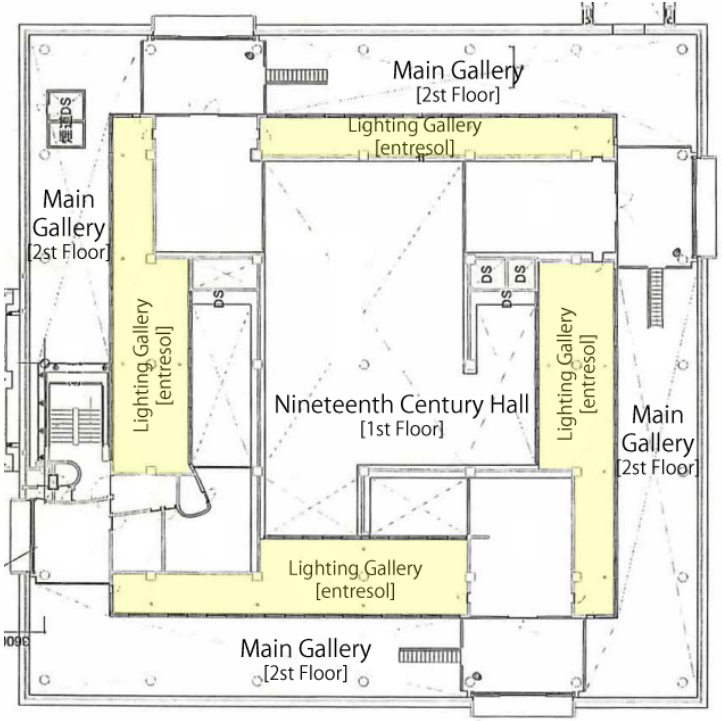
Other recent samples…calculated by Radiance

National Museum of Western Arts in Tokyo was originally designed by French Architect, Le Corbusier, and has just been registered as the World Heritage with his other works this summer.

An investigating committee for restoration was organized in Architectural Institute of Japan in 2009.
The purpose of our study was to investigate the possibility to restore the clerestory windows to original form for the preservation of authenticity, within the scope of conservation requirements of museum's collections.

NATIONAL MUSEUM OF WESTERN ARTS IN TOKYO

The planar configuration is square, and at the center of the building there is a Nineteenth Century Hall which has a double-hight structure.



NATIONAL MUSEUM OF WESTERN ARTS IN TOKYO

This hall has a triangular cone skylight which brings natural light from the northern sky.

屋上：19世紀大ホール
SKYLIGHT

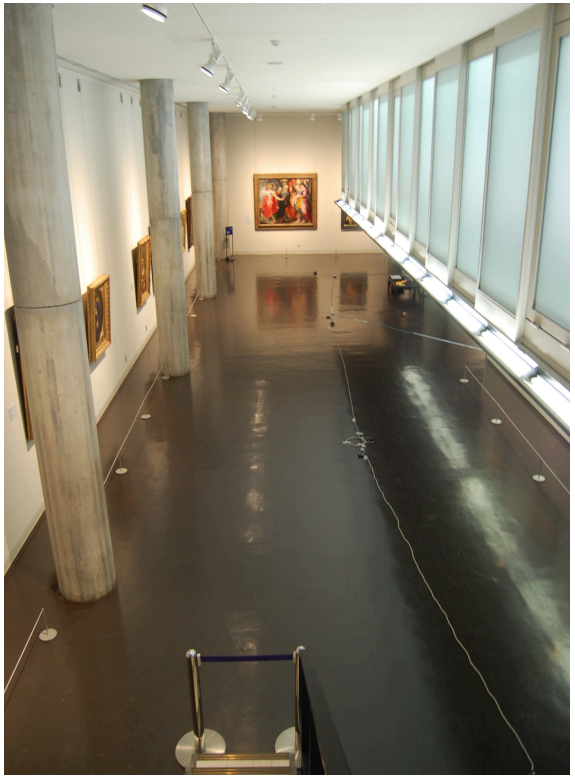
19 century hall

NATIONAL MUSEUM OF WESTERN ARTS IN TOKYO

19 century hall

NATIONAL MUSEUM OF WESTERN ARTS IN TOKYO

A main gallery on the second floor is approached by a ramp in the Nineteenth Century Hall. This gallery encircles the Hall and there is an entresol - lighting gallery - that wraps around the Hall at half the height of the second floor.



NATIONAL MUSEUM OF WESTERN ARTS IN TOKYO

In original design natural light entered from the high side light placed on the entresol floor and fills the main gallery on the second floor and the Nineteenth Century Hall.

Now its glazings have been painted with the intention of excluding daylight completely and fluorescent lamps are now used instead of natural light.

NATIONAL MUSEUM OF WESTERN ARTS IN TOKYO

Top Lights:

NATIONAL MUSEUM OF WESTERN ARTS IN TOKYO

Lighting Gallery : now

NATIONAL MUSEUM OF WESTERN ARTS IN TOKYO

The main problems of the original spaces are strong sunlight and reflective glare which is caused by the location of the Lighting Gallery.

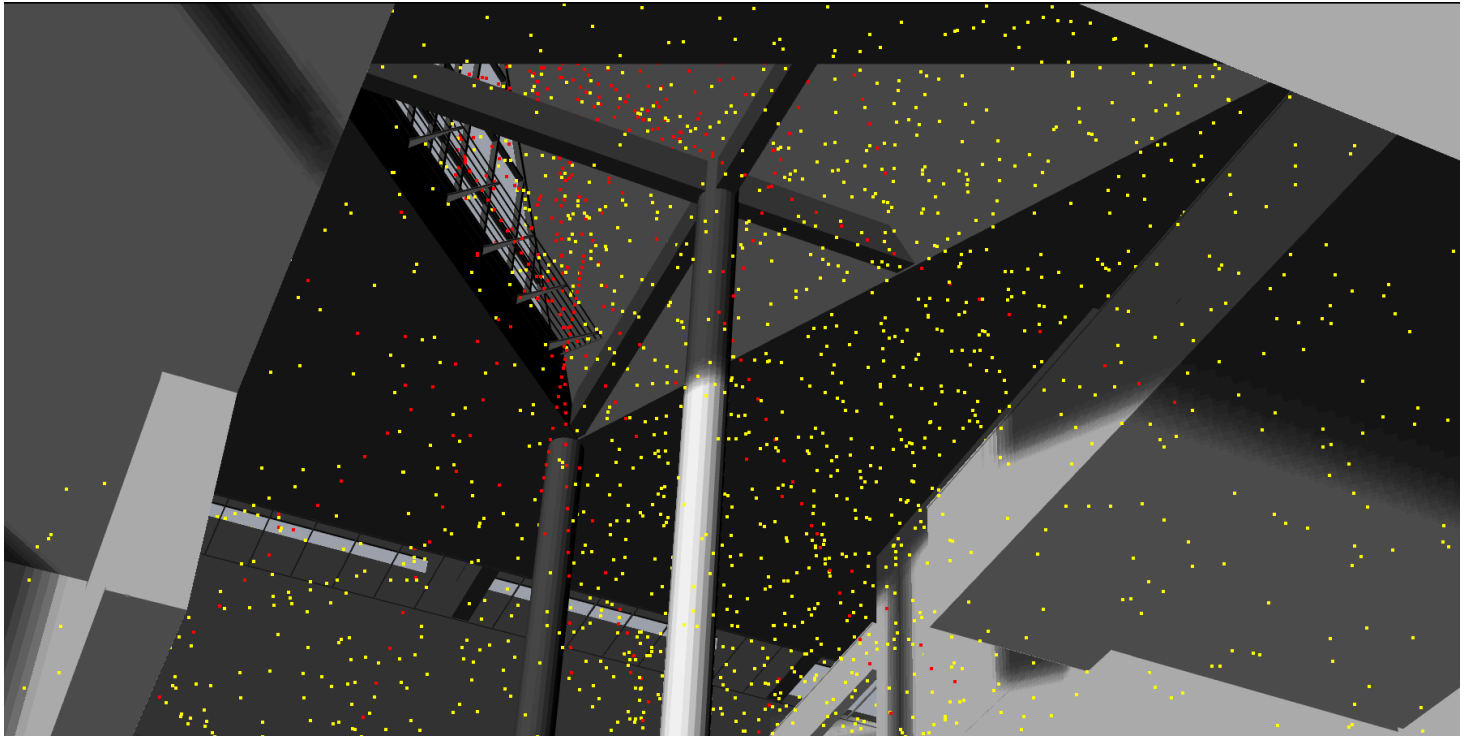
One of the proposals for the renovation is the reintroduction of daylight by using blinds.

Annual daylighting environments were caluculated by Radiance with Typical Annual Weather Data (TWD9302/L) in Tokyo area , to verify the effect of these blind systems.

NATIONAL MUSEUM OF WESTERN ARTS IN TOKYO

RED: Triangular Cone Skylight

YELLOW: Lighting Gallery



Future Works

We would like to do an interview survey whether architects use it efficiently for their preliminary design of buildings.

Quantitative analysis will be necessary.

We could try an animation of photon flow.

Thank you for your attention.