A three-dimensional expression of light flow in colour using photon mapping

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When I meet good architecture all around the world, there is always a good light there. Sometimes, as soon as I step into architecture, I feel confused as to “What is this mysterious comfort attributed to?”. At that time, vague light particles should be present there. Architectural lighting design a task of thinking how to create a comfortable light environment like this. (Quotes from "Kaoru Mende + LPA architectural lighting method")

I would like to create the way to express this feeling that the designer is looking for.
The History of Three Dimensional Expression of Light

In 1939, "THE LIGHT FIELD" --by A. Gershun

Propose an expression method of distributed light in space.

In this paper, the concepts of light field, scalar illuminance, and light vector were born.
The History of Three Dimensional Expression of Light

In recent years, expression of light field has been drawing attention to create a human centric environment.

In 2016, "The Global Structure of the Visual Light Field and its Relation to the Physical Light Field" --by T. Kartashova

- Confirmed that the physical light field and the visual light field are slightly different but similar.

The visual light field: Field of light perceived by people

Many expressive methods have been considered to describe the human-centric light environment.
The previous report in 2016 Radiance workshop

We put some invisible filter made of trans material in the architecture model on the grid, and when a photon hits this filter, its position information will be recorded. We used Radiance5 to make photon.

We can succeeded the expression light like…
The previous report in 2016 Radiance workshop

Pantheon in Rome

Sunpu church in Japan
The previous report in 2016 Radiance workshop

Notre Dame du haut in France

Le Thoronet abbey in France
Moreover, we confirmed the relationship between the density of photons and the scalar illuminance. They have a positive correlation with scalar illuminance, but we could not calculate the absolute value of scalar illuminance from the density of photon at arbitrary points.
In this report

In this report we will present two topics.

1. We linked the photon distribution to the absolute value of scalar illuminance.

2. We make a new method to depict the photon flow in RGB colour separately.
Photon distribution and the absolute value

<Method>

To confirm the relation between photon distribution and absolute value, we compared the scalar illuminance value obtained from cubic illumination and number of photons at the same points in a simple room.
Scalar illuminance is an illuminance over the surface of a sphere. This value can be calculated by using cubic illumination and 5 formulae below.

\[
\begin{align*}
\text{Vector component of each coordinate axis} & = E(x+) - E(x-) \\
\text{Component of vectors} & = \sqrt{E(x)^2 + E(y)^2 + E(z)^2} \\
\text{Symmetric component of each coordinate axis} & = \frac{E(x) + E(y) + E(z)}{3} \\
\text{The average of symmetric components} & = \frac{\text{average}}{4} \\
\text{Scalar illuminance} & = \frac{\text{average}}{4}
\end{align*}
\]

In reference to “Lighting by Design” by C Cuttle
Photon distribution and the absolute value

<From photons>

1. Set the photon port
2. Emit photons from photon port to the room
3. Count the number of photons on the sphere
Photon distribution and the absolute value

In order to count the number of photons on the sphere, we make a virtual sphere using antimatter material. After emitting photons into the space using photon port, only photons on the sphere are taken out.

```
void trans filter0
0
0
7 1 1 1 0 0 0.99999 1

void antimatter filter
1 filter0
0
0
```

Material information
Photon distribution and the absolute value

Most of the light rays intersect twice with spherical surfaces, but since the antimatter material records only photons that incident from the front side, it never counts photons in duplicate.
Photon distribution and the absolute value

\[ E = \frac{N \times W}{A} \times L \]

- **E**: Scalar illuminance
- **N**: Number of photons
- **W**: Each photon’s energy (refer to header information)
- **A**: Surface area of virtual sphere
- **L**: Luminous efficacy (=179)

The energy is calculated by assigning this RGB value into the following equation.

\[ W = R \times 0.265 + G \times 0.67 + B \times 0.065 \]
Photon distribution and the absolute value

The right graph shows the scalar illuminance calculated by the cubic illuminance and the number of photons.

We confirmed that the photon distribution and the absolute value are linked.

We can estimate the absolute intensity of light environment from the appearance of photon density.
Depict photon flow in RGB colour separately

<Background>
For human perception, not only the intensity of light but also the colour of light should be an important aspect.

<Aim>
Making it possible to depict the photon flow in RGB colour.
Photon flow in RGB colour

<method>

Materials of the analysis space and light source are set separately for RGB, and RGB photon are acquired by using photon filter which antimatter material is applied.

In order to approximate human perception, the ratio of the emission amount of RGB photon is R:G:B=0.265:0.67:0.065.
Photon flow in RGB colour
Analysis at Villa Müller

Credits and Data
Architecture title: Villa Müller
Architecture type: Private House
Location: Prague, Czech Republic
Design: 1928 - 1929
Construction: 1929 - 1930
Architect: Adolf Loos
Analysis at Villa Müller

Characteristics

1. Raumplan

“Raumplan” is to think of the room layout of houses as a three-dimensional figure, instead of as floor plans in a conventional way.

Rooms are continuously connected.
Analysis at Villa Müller

Characteristics

2. Material

Characteristic materials and colors are used for each room.

- Characteristic interior decoration is given for each room.
Analysis at Villa Müller

Main bedroom

Bathroom

Children’s room

Staircase

Summer breakfast room

Dining room

Ensemble hall

Entrance room
Analysis at Villa Müller

<Purpose>

1. Can we depict light flow and distribution in complex space using our new method?

2. Confirm whether this method using Photon filter is effective for description of light in space.
   - Compare the impression of the analysis result using photon filter with the impression when actually visiting.
Analysis at Villa Müller

<Method>
Make the model in Rhinoceros
↓
Convert the model into radiance format
↓
Apply the material (We prepare 4 types of material data, one of them has all RGB values, and others have only R, G, B value respectively.)
↓
Emit photons using mkpmap
Analysis at Villa Müller

(Method)
↓
Get photon’s coordinate using `pmapdump`
↓
Enter coordinate data in Autodesk’s Recap

Rhinoceros model
Analysis at Villa Müller

Analysis space

Dining room

Main hall
31 August 08:00
145 [lm/photon]
290 [lx]
297 [lx]
151 [lx]
31 August 10:00
372 [lm/photons]
488 [lx]
504 [lx]
360 [lx]
31 August 14:00
273 [lm/photon]

618 [lx]
648 [lx]
450 [lx]
31 August 16:00
179 [lm/photon]

554 [lx]
541 [lx]
389 [lx]
Conclusion

<Advantage of this method>
It became possible to depict the flow and density of light in three-dimensionally way.

In addition, we can estimate the absolute intensity of light environment from the appearance of photon density.
Conclusion

<Advantage of this method>

This technique using photons can read light flow, light density and physical values. This means that this method could have some advantages to estimate the lighting environment.

Furthermore, it became possible to express the light colour distribution using photons in a space. These characteristics will help to describe the human-centric light environment.
Future works

I would like to confirm whether the light environment expressed by photons is related to human perception through some subjective experiments in near future.
Thank you for your attention.