Cubic Model Expression of Daylighted Environment

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ABSTRACT

The purpose of this study is firstly to show the outline of 'Cubic Model' that can visualize the condition of 3-dimensional light distribution as a systematic expression such as density of light and direction of light and secondly to simulate various lighted environments, especially daylighted environments by 'Cubic Model' and finally to explore an easy grasping system of 3-dimensional lighting environment. As a result of this study, the followings were clarified: 1) The essence of spatial light distribution can be easily seized with 'Cubic Model's simple indication. 2) 'Cubic Model' enables comparing among many different lighted conditions. 3) 'Cubic Model' has a possibility corresponding to many dynamic daylighted environments.

INTRODUCTION

Recently, in the lighting technology field, people tend to attach great importance to the qualitative aspect of lighted environment, especially daylighted environment. Due to this trend, it becomes much more essential for lighting planners and designers to be conscious of 3-dimensional characteristics of light, for example, direction of light as well as density of light in interior spaces. For that reason, many visual expressions that show 3-dimensional characteristics of light have been explored. There are two approaches for grasping and expressing such characteristics of light. One is to make photo-realistic lighting images based on accurate computed calculations. Another one is to make 3-dimensional visualizations of photometric quantities as scientific scalar and vector expressions based on measured data or calculated results. In the former case, it is pointed out at issue that photo-realistic images are easy for understanding lighted environment but does not express all parts of the space. In the latter case, it comes in question form as to the expressions are not understandable even if those are the 3-dimensional lighting properties. In consideration of both of described-above two approaches, we developed a 'Cubic model expression' that expresses the essence of 3-dimensional properties of light as direction of light and density of light without using vector expression.

The purpose of this paper is to show the outline of 'Cubic Model' and to simulate various spaces, especially daylighted spaces by using 'Cubic Model', and to explore the possibility of the model corresponding to dynamic daylighted environment.

OUTLINE OF CUBIC MODEL

Concept of Cubic Model

Main Concept of Cubic Model is based on the consideration that 3-dimentional lighting property should be approximately expressed by composition of brightness and darkness as well as appearance seen through the human visual perspective. Figure 1 shows the basic concept of Cubic Model. Various light conditions and/or various lit spaces are normalized with the same format like “Rubik’s Cube” as a gathering of the 27 unit module cubes. The three-dimensional bright and dark pattern of each space is displayed on the format.

There are the following main advantages in forming Cubic Model:

1) The variables used in the calculations become constant by modeling cube-unit space.

2) It becomes much easier to compare their light distribution patterns because many different interior spaces are converted into the same shape with sets of unit cubes,

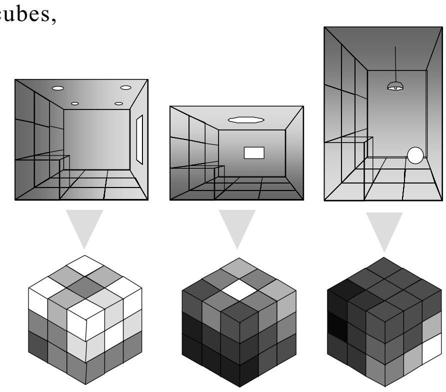


Figure 1 Basic concept of the Cubic Model

The deriving process of the Cubic Model is as follows. First of all, The actual interior space is measured to get some dimensional and photometric data. The data was modeled for Calculation and Visualization by cube unit (Figure 2). And then, calculations on the cube unit and final visual expression by the colored cubes are performed in turn by the program on the computer.

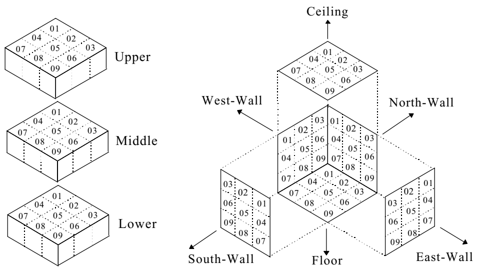


Figure 2 Composition of the modeled space

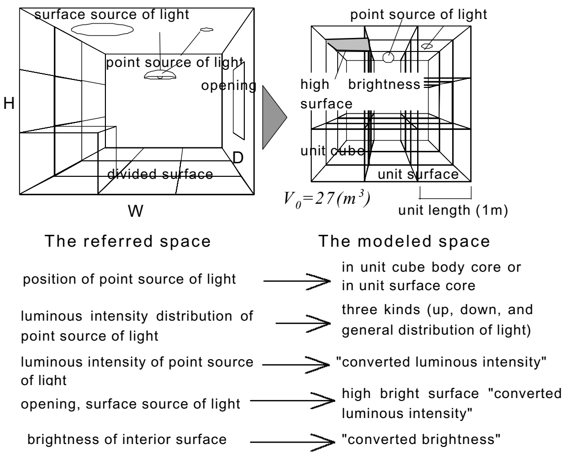


Figure 3 Correspondence of the referred space and the modeled space

A way of measuring the referred space

The referred space is divided into 27 small blocks and each of its 6 surfaces into the rectangle pieces, and each individual block and rectangle (54 pieces on interior surface) is numbered in order (the left of Figure 3). After that, the photometric data on the

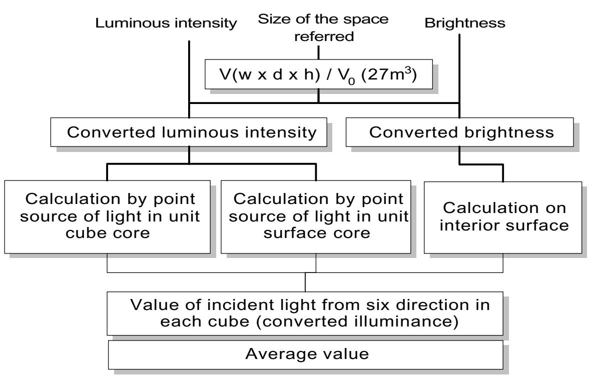


Figure 4 Calculation process of the Cubic Model

divided blocks and the divided surface (brightness measured from the center of the space, light source arrangement, luminous intensity, etc.), the size of space (width, depth, and height) are obtained.

Calculation process by computer program

In the computer program (MS-Excel and Visual Basic for Application), the following three calculation processes are executed, using the modeled photometric quantities based on ratio of the referred space volume to modeled space volume (see Figure 2, Figure 3 and Figure 4).

1) The modeled optical amount (Hereafter, it is assumed 'converted illuminance' which enters in each cube is calculated by unit-sphere method for illuminance calculation using the 'converted brightness' on interior surface.

2) 'Converted illuminance' that enters in each cube is calculated by inverse square law of distance using 'converted luminous intensity' of the point source of light existing in the midair.

3) 'Converted illuminance', which enters in each cube, is calculated by inverse square law of distance using 'converted luminous intensity' of the point source of light existing on the interior surface.

Three processes of the above-mentioned are integrated, 'converted illuminance' of each cube entering from six directions is calculated, and this average value is obtained.

Visual expression of the calculated results

The average values ('converted illuminance') calculated in each cube are expressed as 'density of light' (left of Figure 5). The values of incident light from 6 directions in each cube ('converted illuminance') are expressed as 'direction of light' (right of Figure 5). Each cube is shown by the bright and dark pattern of 10 steps. The density of light is understood from the density of the color in each cube and the direction of light is understood by the difference between bright colored surface and dark colored surface in each cube.

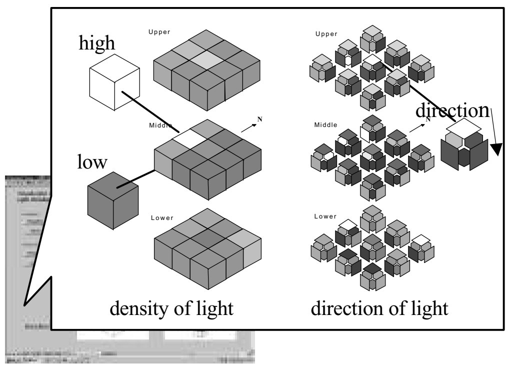


Figure 5 Visual expression of the Cubic Model

APPLYING CUBIC MODEL TO ACTUAL SPACES

Outline of measurements in actual spaces

To apply Cubic Model to the actual spaces, some measurements are needed as already described. Brightness measured from center of the space (54 points), light source arrangement, luminous intensity, luminous intensity distribution and the volume of the space are all necessary data in case of an artificial illumination. The position and the attribute of the source of light are not needed in case of the daylighted illumination. Figure 6 shows the outline of the measurement in actual space.

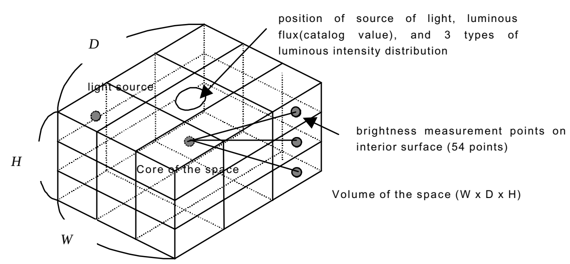


Figure 6 Outline of measurement to actual space

Measured rooms and illumination patterns

In this research, two rooms were measured. The measured spaces are a conference room of university (left of Figure 7) and Japanese style room 'washitsu' of historical building (right of Figure 7).

In the conference room, two artificial illumination patterns and the daylighted illumination were measured. Two artificial illumination patters (all lighting and a row of north side lighting) were measured on September 30, 1997. The daylighted illumination was measured six times every 2 hours from 8:00 to 18:00 on March 22, 2000.

In the Japanese-style room 'washitsu', daylighted illumination (natural lighting) was measured once at 9:30 on September 27, 1997.

One or two people carried out measurements, and each measurement required about 20 minutes. The data obtained by the measurement was input to the Cubic Model program, and the expression of 'density of light' and the expression of 'direction of light' were derived.

Application results of the model

First of all, to confirm basic meaning of the Cubic Model, the model expressions of artificial illumination patterns in the conference room and the model expression of daylighted illumination in Japanese-style room are considered. Then, the model expressions of dynamic daylight change according to the time change in the conference room are analyzed as the main consideration of this research.

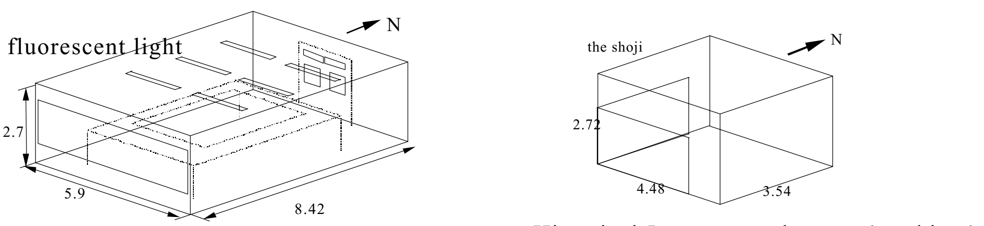
In the model application result of all lighting of the conference room (Figure 8(a)), we can see to darken gradually toward from the upper part of the space to the lower side of the space. This appearance can be roughly understood from the left of Figure 8(a) (density of light) and also understood from the right of Figure 8(a) (direction of light) in detail. In the model application result of a row on the north side lighting (Figure 8(b)), the appearance which darkens gradually from the north part of the space to the lower part of the space is shown. In this case, it is well understood that this space has a horizontal direction of light, especially from right of Figure 8(b).

In the model application result of the Japanese-style room 'washitsu' (Figure 9), light enters strongly from the south and the west side opening, and the light is reflected by mat 'tatami'. We can see the appearance that darkens from the lower part of the space to the upper part of the space. This state is opposite to the case of artificial illuminations (Figure 8) where light is distributed from the upper part.

From described above analysis, the feature point of Cubic Model is to be able to compare among various conditional lit spaces.

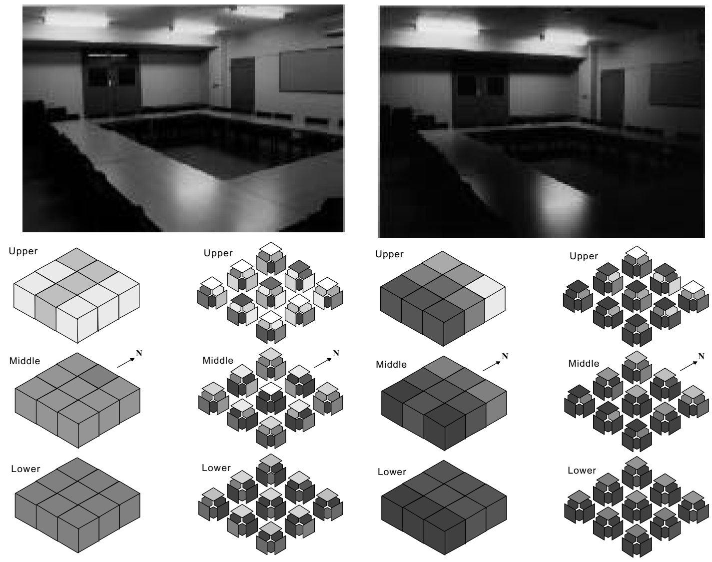
Here, the model application result of daylighted environment change according to time chage in the conference room is considered in detail by 6 model expressions and 6 photographs.

At first, we roughly see Figure 10(a)-(e). The



conference room | Historical Japanese-style room 'washitsu'

Figure 7 Measured spaces



(a) all lighting (b) a row on north-side lighting

Figure 8 Model expressions of conference room

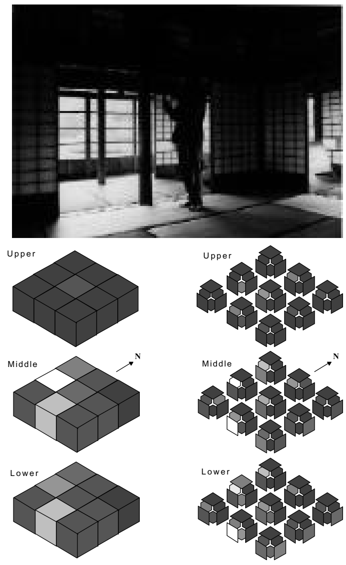


Figure 9 Model expression of historical Japanese style room (natural lighting)

appearance that has darkened from the window side in the south to the northern part of the room can be confirmed from each expression. It can also be confirmed that the entire space become bright from 12:00 to 14:00 and become dark from 16:00 to 18:00.

This tendency concretely is seen as follow. It is seized that the sunlight enter from the east, and the southwest part is bright at 8:00, focusing on the left of Figure 10(a) (density of light). Moreover, seeing the right of Figure 10(a) (direction of light) in detail, we can grasp that the light from the ceiling is weak.

At 10:00, it can be seen that light enters gradually from the south, and the northern part of room interior has lightened from left of Figure 10(b). And it can be well confirmed that light from the southern part of the ceiling has strengthened more than the right of Figure 10(b) (direction of light). It is guessed the reason is that the sunlight enters gradually from the upper part and reflects in the desk arranged in the south, and the ceiling becomes bright.

As to the left of Figure 10(c) at 12:00 and the left of Figure 10(d) at 14:00, these expressions are so similar that the pattern of light distribution can be considered the same. However, we can confirm that there is a place where stronger light enters from the south by seeing the right of Figure 10(d) (direction of light) at 14:00 in detail. This appearance is not confirmed from the right of Figure 10(c) (direction of light) at 12:00.

In Figure 10(e) at 16:00, we can see that the incident light from the west causes the complex light distribution.

At 18:00 in Figure 10(f), we can't confirm daylighted illumination except for leakage light from the external.

From the above-mentioned consideration, the density of light and the direction of light expression of Cubic Model can be effective way for grasping complex appearances of the daylighted situations by referring to each other expressions according to the time axis.

DISCUSSION

Here, some effectiveness and problems of Cubic Model when the model is applied to various lighted environments are examined based on the application results described above.

First of all, Cubic Model can extract the essence of 3-dimensional illumination properties though accuracy is sacrificed to some degree. Moreover, Cubic Model in the present stage is located as a simulation tool for evaluation based on the measurement value. The validity of the model expression has already been examined by the comparison between the measurement result of the space illuminance and the results of model expression.

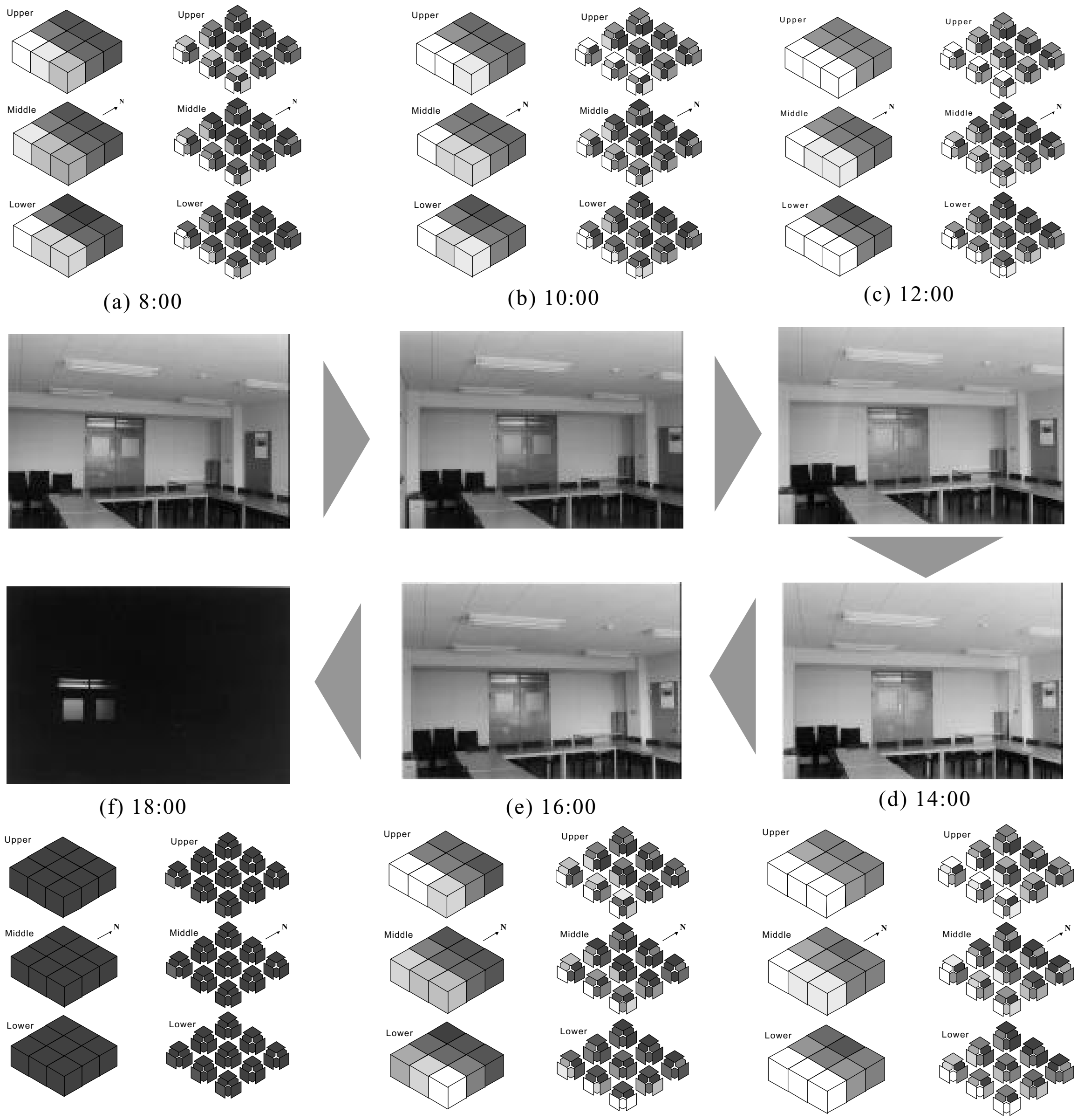


Figure 10 Model expressions of conference room with time axis

Next, we arrange the comparison between the expression of Cubic Model and the expression of lighted environments based on exquisite calculation such as photo-realistic computer graphics. As to the calculating time, Cubic Model enables shortening the calculation time to the time for the computer graphics etc. by making the variable a constant. As to the expression range of the 3-dimensional space, Cubic Model can display the entire lighted space, but the display by computer graphics can't do that. On the other hand, scientific expressions (visualizations) can show the measurement value and the calculation value as 3-dimensional, but these expressions are not intuitive because the display that uses the vector is not understood easily on the 2-dimensional screen. In the Cubic Model, the model expression 'direction of light' can be shown as 3-dimensional and intuitive expression by the combination of different color plane (without using vector).

In addition, the advantages when Cubic Model is applied to the various appearances of the daylighed spaces are examined here. Though Cubic model expression is a rough display, it is easy to understand the density of light in various conditions when the position of the sun is considered. The appearance of the daylight which changes into the complexity like the evening can be understood more clearly by referring to the Cubic Model expression 'direction of light' in detail according to the time change.

CONCLUSIONS

In this research, a cubic model was applied to various lighted situations that contained daylighting, and the following were clarified.

1) The essence of 3-dimensional light distribution can be easily seized with 'Cubic Model's simple indication (density of light and direction of light) without using the vector expression.

2) 'Cubic Model' enables to compare among many different lighted conditions regardless of the artificial illumination or the daylight illumination.

3) 'Cubic Model' has a possibility corresponding to many dynamic daylighted environments.

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