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Time handling in inverse daylighting for CAAD

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Abstract

This paper presents an integration of time dimension in an inverse natural lighting model. This model allows to aid the design of building openings starting from the designed volume and lighting intentions. As natural lighting evolves according to the hour of the day and the day of the year, it is necessary to take into account that the lighting intentions expressed by designers might evolve through time. The problem is to choose the way of mixing the lighting intentions or the solutions of inverse lighting simulation in order to produce useful results for designers. We propose to compute separatly individual inverse lighting at each time step in order to get an individual evaluation map, and to combine the results in a final time evaluation map. This time evaluation map allows to read easily the addition of several inverse lighting simulations, and to compute an opening shape which is intended to be used as a basis for the opening design. Our method is illustrated through test cases in order to show the inverse lighting process with time integration.

Categories and Subject Descriptors (according to ACM CCS): I.3.5 [Computer Graphics]: Physically based modeling I.3.8 [Computer Graphics]: Applications

1. Opening design problem

Designing forms and shapes from light data is a well-known problem in the computer graphics community. More precisely, the problem addressed in this paper is to compute building opening shape from indoor lighting in buildings (Figure 1), taking into account the evolution of lighting over time. Such an approach needs the lighting intentions to be translated in scene lighting properties, and these lighting descriptions to be processed by an inverse model in order to obtain opening shapes. A lighting intention is a graphical representation of the light desired in a designed building.

The processing of lighting intention is an inverse lighting problem. Previous works can be classified following inverse problem type [MG97] according to whether the required element depends on the scene geometry - inverse geometry [MBK95], the reflectance properties of surfaces - inverse reflectance [YM98, KPC93], or the position and intensity of light sources - inverse lighting [CSF99, SDS*93, KPC93]. For a complete review of inverse rendering problems, we refer to [PP05].

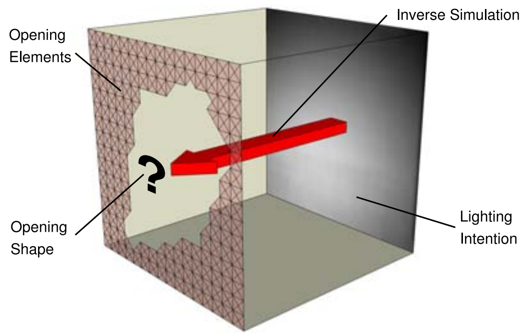

Figure 1: *Opening design problem.*

Opening design problem is a geometric reconstruction from lighting intentions, and is addressed as an inverse geometry problem by [MBK95]. Nevertheless, the expression of lighting intentions over time in these models is very limited as the designer can specify only one lighting intention. We represent a lighting intention over time by several graylevel textures, each of these containing a time tag.

Section 2 describes our inverse lighting model based on three steps: anisotropic source generation, lighting evaluation and opening element selection. Section 3 presents two test cases before to conclude in section 4.

2. Inverse lighting model

Our goal is to compute raw opening shapes from several lighting intentions. The lighting is considered according to daylight factor formula with sun/sky component (*SC*), external reflected component (*ERC*) and internal reflected component (*IRC*). We proposed a source emittance approach based on a pin-hole model and an image distance measurement to compute raw opening solutions [TMH08]. Internal interreflections are put aside for now, nevertheless we keep in mind that we will have to integrate *IRC* in our model.

The face where the designer can put windows or skylight is named "opening face". The opening face is meshed into n patches named "opening elements". The light coming through an opening element is considered as the light contribution of this opening element. As this lighting contribution is different according to the incoming light direction, an opening element is an anisotropic light source. The $SC + ERC$ lighting on indoor faces of several opening elements can be computed as a linear combination of their lighting contributions. Starting from these facts, our method is divided in three steps:

- Generation of light coming through each opening element.
- Evaluation of each opening element according to its light contribution to indoor lighting.
- Selection of an opening element subset in order to create an opening shape which produces a lighting close to the lighting intention.

2.1. Opening element lighting

The lighting contribution of each opening element is computed with a pin-hole model in order to obtain lighting from the sky (*SC*) and the surroundings (*ERC*) (Figure 2). Our model can be seen as a kind of hemi-cube [CG85] centered on an opening element.

Each sky patch, respectively surrounding building patch, can supply *SC* lighting (E_{SC}), respectively *ERC* lighting (E_{ERC}), through an opening element to the indoor faces. We set a relation between the sky patch luminance L and the indoor illuminance E_{SC}, through a relation between the luminous flux Φ_r received by an opening element and the luminous flux Φ_e emitted by an opening element.

$$E_{SC} = \int_S \frac{L \cdot cos^3\alpha \cdot cos\,\beta \cdot \tau}{d^2} dS \qquad (1)$$

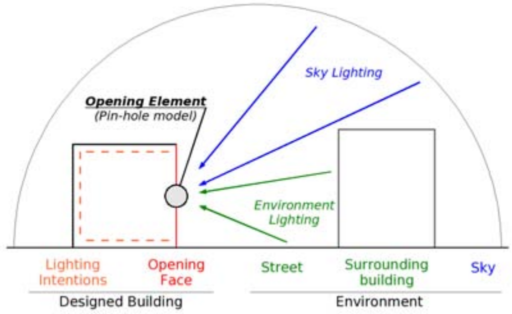

Figure 2: *Inverse lighting based on pin-hole model.*

with α the angle between the indoor lighted area normal and the direction from the indoor lighted area to the opening element, β the angle between the opening element normal and the direction from opening element to the sky patch, τ the transmittance of opening element, d the distance between the opening element and the face containing indoor lighted area and S the opening element surface.

E_{ERC} is obtained from former relation which is modified to set up a relation between the environment patch emittance M and the indoor illuminance E_{ERC}. We consider all external reflections with Lambert's law ($M = \pi \cdot L$).

A picture of the outdoor scene from the opening element centre represents the light passing through this opening element into the indoor space. In one rendering step, the light contribution of all outdoor patches through one opening element on one face is computed. With this approach based on a perspective projection, we avoid a time consuming meshing of the indoor faces to compute the position, size and shape of the illuminated area.

2.2. Opening element evaluation

The opening element evaluation determines the interest of the light brought by an opening element in order to generate the desired lighting. The opening element evaluation is based on a distance measure between the lighting intention E^{int} and the light contribution of an opening element E^{op}. Two descriptors are extracted from the histogram of the squared error image: mean $\overline{\Delta E}$ and standard deviation $\sigma_{\Delta E}$.

Former values are summed and the result is attributed to each corresponding opening element and coded in a graylevel scale. The opening element set associated to their values constitutes the evaluation map of the opening face related to one indoor face at one moment. The more an opening element is dark, the more the evaluation is good, and therefore suitable to produce the desired lighting. When the evaluation maps at each time step are computed, they are concatenated in order to compute the time evaluation map. We choose the mean as concatenation operator because it shows the overall idea of several lighting intentions.

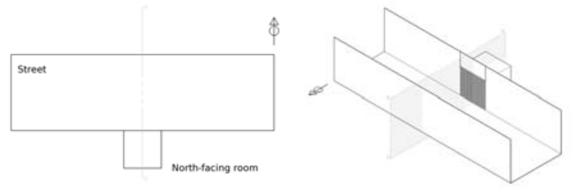

Figure 3: *(left) North-facing room and street (right) Axonometric view.*

2.3. Opening element selection

The evaluation map or time evaluation map are considered as an input data at the selection step. The problem is to know how we can select the opening elements in order to produce an opening shape. The solution is intended to be a starting point for an architect designing the actual opening. An automatic selection method computes a threshold value t in order to reach the light quantity needed in lighting intention. From this threshold value, a binary segmentation of the evaluation map is automatically performed and displayed. Therefore the designer can immediately appreciate the theoretical opening shape that has been created. An interactive selection interface allows the designer to tune threshold value in order to modify the light quantity and the opening shape.

3. Test cases on September 21st

These test cases show how our inverse lighting model reconstructs an opening from several lighting distributions produced by one or several original openings. The situation is a room with a north opening face located in an east-west street (47° N) (Figure 3). Sky luminance is set on September 21st under a clear sky. Direct lighting simulations are computed with Solene [MG02] to get the original light distribution in the tested room at each time step (8am, 12pm and 16pm). The light distribution of the five indoor faces are considered as the lighting intentions.

3.1. Coherent lighting intentions

In this first test case, lighting intentions come from a direct lighting simulation (Figure 4) with the same opening (Figure 6 a). The evaluation maps are computed for each time step (Figure 5) so as the time evaluation map (Figure 6 b). The time evaluation map is segmented by the user through the interactive selection tool (Figure 6 c), and the lighting is immediatly displayed in order to show the lighting produced by the reconstructed opening (Figure 7). The lighting distribution and values produced by the reconstructed opening are close to the original ones.

3.2. Incoherents lighting intentions

In a second simulation, each inverse lighting simulation is associated with a lighting intention from different openings

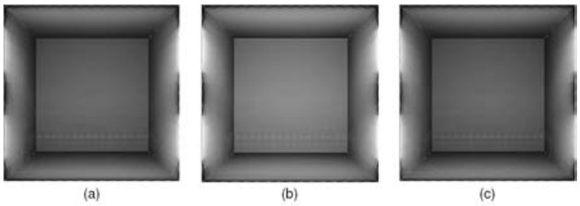

Figure 4: *(a, b, c) Intentions at 8am, 12pm and 16pm.*

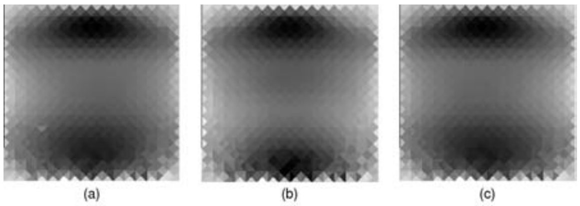

Figure 5: *(a, b, c) Evaluation maps at 8am, 12pm and 16pm.*

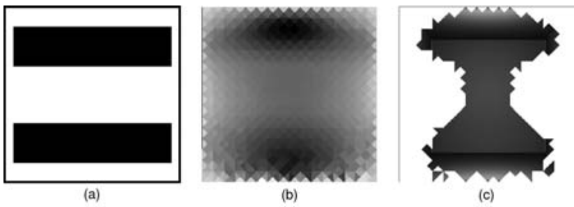

Figure 6: *(a) Original opening (b) Time evaluation map (c) Binary segmentation of b.*

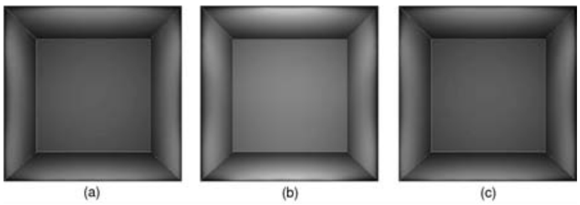

Figure 7: *(a, b, c) Relighting with reconstructed opening at 8am, 12pm and 16pm.*

at corresponding hour. Therefore, there is no a priori coherence in the evolution of the lighting intention. As an example, the lighting simulations at 8am, 12pm and 16 pm are associated with a the lighting intentions produced by a horizontal opening, a diamond shape opening and a cross shape opening, respectively (Figure 8). The evaluation maps are computed (Figure 9) as well as the time evaluation map (Figure 10 a). The binary segmentation of this time evaluation map produces an opening shape where we can retrieve some geometric properties of the previous segmentations (Figure 10 b) : an horizontal shape and a hole on the high part of the opening face. The interactive user interface allows to compare the lighting produced by this opening

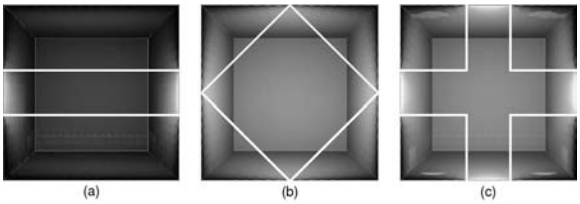

Figure 8: *(a, b, c) Intentions at 8am, 12pm and 16pm.*

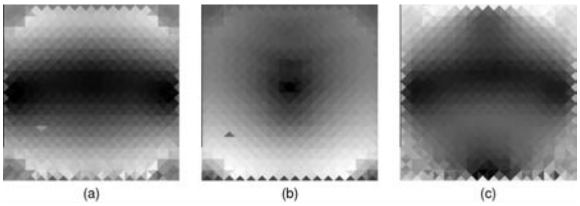

Figure 9: *(a, b, c) Evaluation maps at 8am, 12pm and 16pm.*

Figure 10: *(a) Time evaluation map (b) Reconstructed opening.*

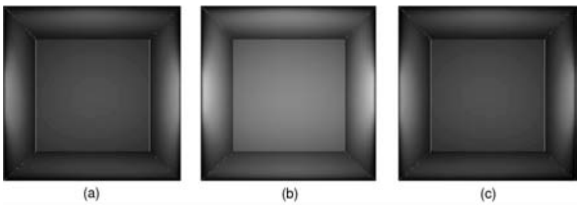

Figure 11: *(a, b, c) Relighting with reconstructed opening at 8am, 12pm and 16pm.*

with the original intentions in order to tune the binary segmentation threshold (Figure 11). These intentions cannot be realized as there are not coherent, nevertheless our model can compute the closest solution with given constraints.

4. Conclusion and Further works

Our main contribution is the integration of lighting intention with evolution over time into an inverse natural lighting model which takes into account lighting with sun/sky and external reflected components ($SC + ERC$). We propose a concatenation of the results of several inverse lighting simulation through the mixing of individual evaluation maps into a time evaluation map. The concatenation operator is tested and a discussion is engaged about the use of other operators.

Where further works are concerned, we look for the integration of interreflections and lighting color. We also need to demonstrate that our model scale to realistic scenes in order to be useful for architects.

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