A GAZE VISUALIZER TOOL

IMPLEMENTATION OF GAZE DATA INTO LIGHTING RENDERING TOOLS USING RADIANCE AND HONEYBEE FOR GRASSHOPPER3D

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ABSTRACT

The Gaze Visualizer tool is an implementation of eye-tracking (gaze) data and a preliminary gaze responsive light driven (GR_L) model, which enables to visualize gaze behavior in a 3D space, in Grasshopper3D. The workflow from obtaining the relevant photometric quantities, retrieving gaze data, intorduction of the GR_L model to the tool and a simple data representation scheme are presented here. The final plugin is easy to use for Rhino/Grasshopper developers with only basic skills, and provides a quick estimations of the gaze respionsive visual comfort in an illustrative way, that gives the user an adequate overview of the glare-free zones in the room.

INTRODUCTION

Considering human needs in relation to indoor environment plays a crucial role in buildings' overall performance. A basic human need is a comfortable indoor environment (Monika Frontczak and Wargocki 2011) such as visual comfort with mainly psychological aspects (Bollen 2002; M. Frontczak et al. 2012). However, investigations on human body responses to indoor conditions proves to be essential (Bluyssen 2013) for better understanding of human needs. Gaze is a volitional or reflexive body response where we direct our line of sight as a visual response to the surrounding conditions. Eye-movement classes such as saccades (rapid shifts) and fixations (longer pauses) coexist with head and body movement to shift our gaze. The full contribution of these effectors (eye, head, body) to gaze ('t Hart and Einhäuser 2009) provides information on visual response to the surrounding visual environment during a real-life task ('t Hart and Einhäuser 2012; Fairchild et al. 2001) such as working in an office.

With each gaze shift when scanning our surrounding environment, a new luminance distribution is introduced across the field of view (FOV). The inherent dependencies of visual comfort on gaze behavior (Clear 2012; Sury, Hubalek, and Schierz 2010; Fry and King 1975; Yamin Garreton et al. 2015; Lin et al. 2015) is underlined by this re-adaptation mechanism (Kokoschka and Haubner 1985), which favorably or unfavorably contributes to visual comfort perception (Guth 1958; Kim and Koga 2004). A constant re-adaptation in a highly contrasted room susceptible to e.g. discomforting glare, affects our overall subjective response to visual lighting conditions such as discomfort glare (DG) (CIBSE 1994), which as well underlines the complexity of visual comfort predictions (S Hubalek and Schierz 2006; Einhäuser et al. 2007; Nuthmann and Einhäuser, n.d.) especially when no inference to visual gaze response.

The necessity of limited luminance ratios in FOV to avoid constant re-adaptation for better work performance have been addressed in some early studies (Kokoschka and Haubner 1985). However, not strong a DG predictor compare to other existing models (Van Den Wymelenberg and Inanici 2014). DG is a condition that is caused by wide range of contrast in FOV that do not impair visibility (International Illumination Commission CIE 2002). However, a negative response and eventual eye strain is caused by the presence of the disturbing lighting condition (Boyce 2014). Several models have been developed to quantify this phenomenon for artificial and daylighting conditions. These models are developed mainly by associating relevant photometric relations linked with visual visibility and luminance contrast (equation 1), as a
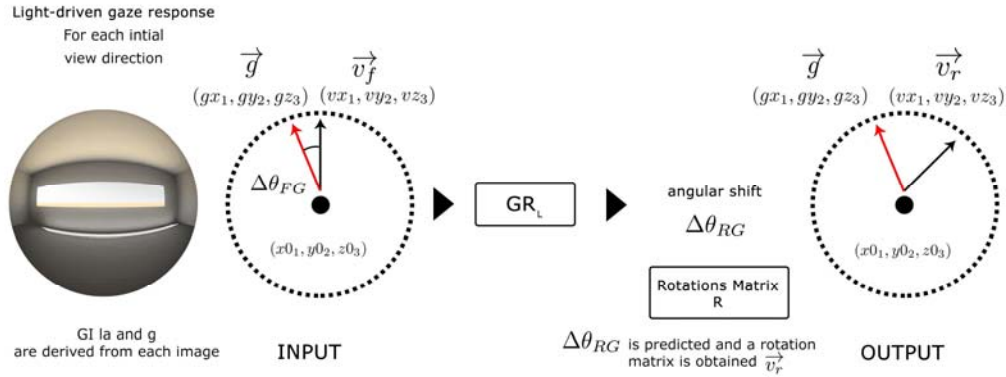
Figure 1 Diagram showing the GR_L model.

shared component, to subjective responses using different measurement scales for each model.

$$DG \approx = \frac{L_s^{exp_1} \cdot \omega_s^{exp_2}}{L_a^{exp_3} \cdot P_i^{exp_4}} \qquad (1)$$

The shared photometric relation indicates that brighter glare source L_s, in contrast with the luminance that the eye is adapted to L_a, depending on its size ω_s and position in FOV P_i, creates a certain risk of glare.

Some recent studies have addressed eye movements (Lin et al. 2015) and its physiological response (Yamin Garreton et al. 2015) in relation to glare and visual comfort. In a similar context, when viewing static images of natural scenes (streets lit with lamppost at night), observers have tended to avoid bright and dark stimulus regions and to direct gaze to regions of medium luminance instead (Nuthmann and Einhäuser, n.d.). Other studies that have investigated the relationship between gaze sand building-induced visual context ,e.g. windows (Sury, Hubalek, and Schierz 2010) or light (Kokoschka and Haubner, 1985; Lin et al., 2015; Vincent et al., 2009), suggest that during a period of office work, gaze is not fixed on an area, e.g. task area (Sylvia Hubalek and Schierz 2004). The gaze shift visual re-adaptation process has been acknowledged by (somewhat arbitrarily) extending gaze directions to a preferred angular range (Jakubiec and Reinhart 2011).

Relationships between gaze, glare and light exposure patterns in the FOV has though been particularly addressed in a series of experimental studies (Sarey Khanie et al. 2016) that have led to a preliminary gaze responsive light-driven (GR_L) model (equation 2) (Amundadottir et al. 2017). This model predicts gaze direction as a function of glare impact (equation 3) and as such represents the first attempt to integrate gaze allocation with glare prediction and daylighting

conditions based on objective measurements of eye movements.

$$\Delta\theta_{RG} = 1.92 + 0.56 \frac{\log GI}{L_m \times \Delta\theta_{FG}} \qquad (2)$$

$$GI = \sum_{i=1}^{n} \frac{L_{s,i} \times \omega_{s,i}}{P_i} \qquad (3)$$

In this model, the direction of the angular gaze shift $\Delta\theta_{RG}$ is defined as the opposite direction to the brightest glare source vector $\vec{g}$ in relation to the initial fixed gaze direction $\overrightarrow{v_F}$ (figure 1). The angular distance between the gaze vector and the glare vector $\Delta\theta_{FG}$, is defined as the dot product of the two vectors. The glare impact GI (equation 2) calculates the effect of all glary patches L_s weighted by their size ω_s and consideration of their position P in the FOV which is adapted to an average luminance of L_m. Finally, in order to obtain the responsive gaze vector $\overrightarrow{v_r}$, a rotation matrix is created based on the predicted angular shift $\Delta\theta_{RG}$.

A rather complex consequent challenge to address in such an integrated approach is to effectively visualize a dynamic property like gaze in lighting design processes. We here introduce a GazeVisualiser tool for lighting rendering which enables to visualize gaze behavior in a 3D space by displaying gaze allocation data points as predicted by GR_L interactively. The same kind of data could in fact also come from an eye tracking. The algorithm behind this tool obtains the intersection point of each gaze vector with the 3D geometry of the space. (Sarey Khanie et al. 2016). Using Radiance image-based simulations (Ward 1992; Wienold and Christoffersen 2006), the vector lines and intersection points are visualized (Sarey Khanie et al. 2016). Alongside this gaze data point, additional information, e.g. fixation duration, photometric properties of the scene, etc., can also be displayed. This paper describes the implementation of the mentioned algorithm to a so-

called GazeVisualiser tool, which can easily be used with the Honeybee plug in for Grasshopper3D.

METHODOLOGY

This section will briefly cover the set-up environment in Grasshopper for generating the high dynamic range (HDR) images that are needed for calculating GI and other photometric values for *Grasshopper*. In *Grasshopper3D*, the *Ladybug* and *Honeybee* plugins are used to make the image based simulation and rendering of HDR images of a 3D model space.

Implementation of the gaze data into lighting rendering tools

Figure 2 shows a simple layout of the implementation process of the Gaze Visualizer tool for Grasshopper 3D. The implementation process consists of 6 main steps as shown in figure 2 and includes components from *Honeybee* and *Ladybug*, which are plugins to *Grasshopper*.
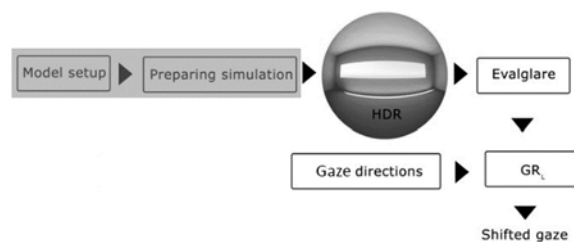

Figure 2 Implementation workflow.

Model Set up & simulation

3D space and model specification

A 3Dimentional geometrical model to be used with the developed tool can be set up in *Rhinoserous* 3D modeling tool. Each surface of the 3D model is defined in *Grasshopper* with the *createHBsurf* component, which allows setting up different reflection properties for walls, ceilings and floors of the 3D model. The window glasses are defined with a transmittance factor. Moreover, locations with an associated weather file and orientation of the model is needed in order to perform an image-based simulation. Finally, a specific day, hour and sky condition needs to be defined. The vp in the 3D model can be set using the point tool at a desired place to define where the occupant's eye is located.

Surface Material

In order to run daylight simulations for all gaze directions and create the needed HDR images, all the surfaces in the 3D model must be assigned a *Radiance* material. These materials determine how the light will interact with the surfaces in the zone. It is possible to use four classes of *Radiance* materials, plastic, metal, trans or mirror, which can be assigned to the 3D model using the *Honeybee*.
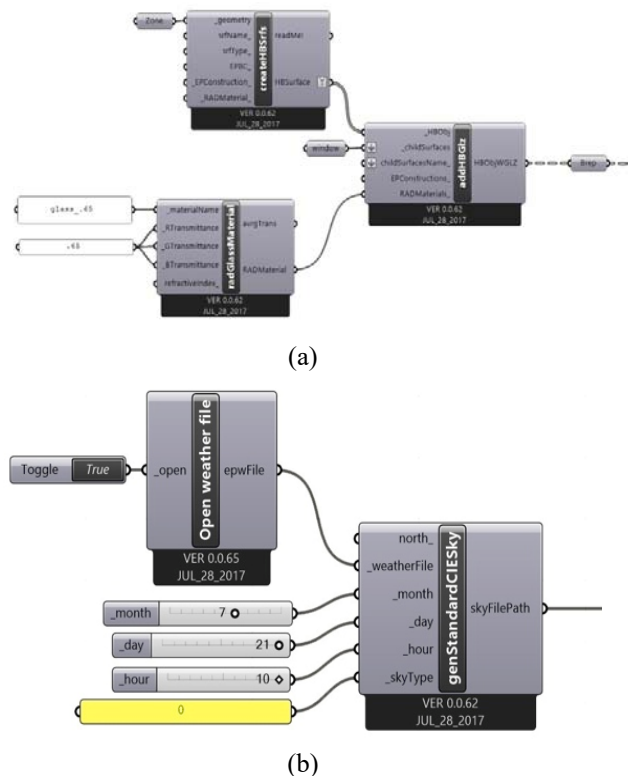

(a)

(b)

Figure 3 (a) Preparing Simulation Geometry and assigning surface material. (b) Generating CIE sky.

The *Masses2Zones* component was used which allows for assignment of several properties to different surfaces. To identify what is a window the *Honeybee addHBGz* component was used (figure 3a). Finally, the sky is generated using *genStandardCIESky* (figure 3b).

Setting the Viewpoint and Gaze Direction

The GR_L model predicts gaze responsive zones based on an initial gaze point (view point vp) and several gaze direction vector $\overrightarrow{v_F}$ spreading over 360 degree span of visible space.

In order to introduce the gaze directions $\overrightarrow{v_F}$ from a certain vp, different methods can be used based on the specification of predefined gaze directions. The allocation of $\overrightarrow{v_F}$ vectors depends on the designer's decision on dividing the space. This decision can be either to divide the space into zone-intervals or to consider specific directions in the room. In premier scenario, a *Ladybug* plugin component *ComfortMannequin* can be used. In this method, the gaze direction of the mannequin (located at vp) is set to rotate with certain determined intervals to cover a whole 360˚ of the spatial span.

In the later scenario, the component GazeViz (figure 4) was introduced to the tool which allows to write in

specific gaze direction coordinates by entering the (x,y,z) of each vector.

Here 9 gaze directions with a 40˚ interval angle to cover the central vision (ergorama) with a reasonable margin has been considered. The nine gaze directions are all starting at the initial vp as assumed occupant's eye level.

Given that the 3D model with all desired set ups has been created, running the *runDaylightAnalysis* introduced in the tool will create the HDR images with respect to each gaze direction (figure 5). These images provide the relevant photometric values with respect to each gaze-directions needed to the GazeViz component. Based on this input data for each gaze directions the responsive gaze vector $\vec{v_r}$ is predicted and visualized in the geometrical 3Dimentional model of the space.

Figure 4 GazeViz components

Figure 5 The HDR 9 images generated for the test zone

Deriving the photometric values using Evalglare

The relevant photometric values as input to GR_L model are derived from HDR images with angular fisheye projection rendered by using advanced physically based light renderings tools such as *Radiance* (Ward-Larson and Shakespeare 1998). These images can then be processed using Radiance -based tools *Findglare* (Ward 1992) or *Evalglare* (Wienold and Christoffersen 2006). Here, the HDR images were obtained using *Honeybee* plugin, which is connected to *Radiance.* To use Evalglare directly from *Grasshopper* a component has been made called *RunEvalglare*, which runs Evalglare and adds the obtained photometric values to a list for each rendered HDR image. The needed input to this component is the working directory, gaze directions and a path to the rendered images.

GAZE VISUALIZER OUTPUT RESULTS

Photometric results

The results from the *Evalglare* can be visualized using the cluster *ColorSrfMap*, containing a cluster of native *Grasshopper* components. The cluster component are using a green-yellow-red color gradient to color the mesh plane according to the output from either the *Evalglare ,e.g. GI,* where the red areas show the highest value in the result list, the yellow the values in the middle, and finally the lowest values are shown in green (figure 6). For the *Evalglare* output values a transformation script were used in order to get the result values as a list instead of strings in order to visualize the different gaze directions without needing to perform a new calculation each time.

Gaze Results

Figure 7 shows an example where gaze directions are shifted as function of the lighting condition in the room for an instance of time. A gaze responsive zone (zone 1) can be detected where most gaze are and where 88% of the gaze directions have been shifted to as result of the lighting conditions. The result is dependent on the time, date and the sky condition.

Figure 6 An example visualizing an Evalglare-output in Rhino

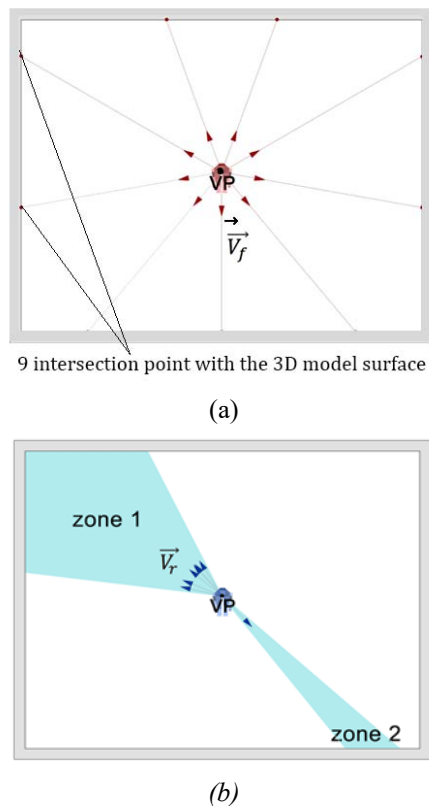9 intersection point with the 3D model surface

(a)

(b)

Figure 7 A schematic representation of the gaze direction results; (a) the initial 9 gaze directions. (b) the shifted gaze directions predicted by the GR_L model.

CONCLUSION

In this paper, we briefly describe the implementation of Gaze data and GR_L model into *Grasshopper* as a tool with mention of several components and the main principles that have been created and used for each step of the working process of the new Gaze Visualizer tool development. The developed tool shows the shifted gaze for one viewpoint in a 360° view range and highlights the gaze responsive glare-free zones in the space.

Several limitations of the developed tool can be mentioned here, which will be further developed in future steps. The current result shows the gaze responsive zones from only one vp. An extension of this feature to a grid of points where the frequency for the shifted gaze could be illustrated with a color map in Rhino is foreseen in future development of the tool. Several additional features such as a legend describing the data and final visualized images with the intersection gaze data needs further development. Finally, a general limitation is the rendering time and running the sub-processes. In a design process, simulation tools need to be quick in order to iterate over multiple design options. However, such limitations are being overcome with the advanced processing power and efficiency in rendering engines. The tool can be downloaded as a plug version for Grasshopper in its current state through the following link: https://doi.org/10.5281/zenodo.1245616

NOMENCLATURE

$L_{s,i}$	Luminance of a glare source [cd/m2]
$\omega_{s,i}$	Solid angle subtended at the eye [sr]
L_a	Adaptation Luminance [cd/m2]
P_i	Position Index of source i
$\vec{g}$	a vector connecting eye to the glare center
$\overrightarrow{v_f}$	a fixed vector connecting eye to the task in front
$\overrightarrow{v_r}$	the predicted responsive vector
$\Delta\theta_{RG}$	Angular responsive gaze shift [rad]
$\Delta\theta_{FG}$	Angular distance between $\vec{g}$ and $\overrightarrow{v_f}$
GI	Glare Impact
L_m	Average luminance in FOV

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