A design decision support tool for visual comfort evaluation under daylighting conditions

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ABSTRACT: Light and architectural design are inseparable. Light plays a major role in the perception of the place. Design for spaces often does not fully consider the setting where the building is placed. This connection with the surrounding environment can turn the space into a place where an occupant feels his existence and sense of dwelling. One of the main reasons a good number of today's buildings are unsuccessful in terms of visual conditions and comfort, because they are only focused on function and structure without considering the quality of the place. In response to this there is growing interest in the study of visually disturbing effects such as glare and poor visual comfort.

Several studies on visual comfort have been performed. Very little research examined movement through a space and time-dependency of daylighting. To address daylighting dynamic conditions, this paper attempts to propose a framework for improving design decision-making by evaluating visual comfort. An immersive case study was used for the framework application.

The case study conducted in this paper was a daylit transitional space represented by a museum corridor. The space was evaluated for visual adaptation and glare control. The developed framework used Grasshopper and its sub components to interface with Radiance and Daysim. In addition to quantitative outputs, special re-representation was used for qualitative analysis to support design decision-making. The research outcomes are expected to provide researchers, designers and decision makers with an approach for designing and re-imagining spaces to improve visual comfort and the quality of the place.

KEYWORDS: Visual Comfort, Daylighting, Decision Support, Museums, Design Process.

INTRODUCTION

"We were born of light. The seasons are felt through light. We only know the world as it is evoked by light… Natural light is the only light, because it has mood… it puts us in touch with the eternal. It is the only light that makes architecture", Louis Khan (Bainbridge & Haggard, 2011, p. 136).

Daylighting can play a major role in resource conservation and occupants' level of productivity, health and comfort. Previous research findings showed that views to the outside provided by daylighting have a strong effect on psychological and physical wellbeing (Andersson, Place, Kammerud, & Scofield, 1985).

While daylight is desirable in most living or working spaces its dynamism can create uncomfortable situations causing visual discomfort. The phenomenon of discomfort glare is recognized as one of the most common visual problem that has not been fully quantified and understood (Seamon & Zajonc, 1998).

Visual comfort in offices was investigated by Osterhaus (2009) using a case study approach. The research findings suggested ways to better integrate computer workstations in daylit offices. Other studies focused on the required conditions for visual comfort in educational buildings (CFEE, 1999). The results of these studies showed a positive relationship between increased daylighting and improved test scores and better student performance. Although there have been many studies on visual comfort, several issues exist when implementing daylight. Interior space quality and users' perception was investigated in a study by Kolokotsa et al. It concluded that future investigations using different prediction techniques were needed to improve the predictive control algorithm (Kim, Han, & Kim, 2009). Visual comfort in transitional spaces under overcast sky conditions was examined by Boubekri in (2007).

Very little studies have considered the daylight time and space dynamics. In addition a small number of glare analysis tools are accessible to non-professionals and may require specialized computing and programming skills.

The main objective of this paper is to improve design decision making through the development of a framework that considers visual comfort and glare. To achieve this objective a framework for visual comfort evaluation in daylit spaces was developed to help designers make better informed decisions.

1.0 METHODOLOGY OVERVIEW

This paper is a part of a research that aims at improving design decision-making through a re-representation tool for visual comfort consideration in dynamic daylit spaces. This paper represents two of the research main phases: 1- framework to evaluate visual comfort, especially in transitional spaces, and 2- an immersive case study approach was used test the framework potential in supporting design decision making.

1.1. Phase1: framework

The framework aims at representing glare and visual discomfort conditions that may occur in a daylit space. The framework main stages are: 1- Data input, 2- Analysis and simulations, 3- Evaluation, 4- Visual comfort condition decision, and 5- Designer final decision on redesigning. The stages are discussed in details in the following subsections:

1.1.1. Data input stage

The designer inputs are: a 3D-model for the space, building site geographical location (a weather file), sky condition, simulation times and days, building orientation, and examined circulation path in the transitional space as explained in Table 1

Table 1: Framework data input.

Variable	Description	Software used
Geographical location weather	The weather file was selected based on the geographical location. Weather files can be downloaded from: http://apps1.eere.energy.gov/buildings/energyplus/weatherdata_about.cfm	DIVA Grasshopper
Sky condition	Clear sky without sun is the default	
Date and time (mm dd hr):	Annual simulation is the default. Specific days and times can be selected depending on the space function, occupancy hours and daylit hours.	
Materials properties	A material file is included in the DIVA plug-in with major generic materials; properties include transparency, color, and reflectance. Custom RADIANCE materials can be added to the original file.	
Building orientation	Default north in Rhino software is pointing up	Rhino
Building geometry (3D-model)	Building geometry and surroundings are exported to Rhino where Grasshopper (Rhino plug-in) can run a series of evaluation simulations. Geometry can be saved as 3D-shapes or meshes, and exported to Rhino.	Rhino, accepting exported files from (3D-max, CAD or Sketch-up)
Simulation points/path	A circulation line or curve in the 3D-model where simulation points are placed horizontally at the eye level (5.6ft) and vertically every (7.7ft) based on the average pedestrian speed per second.	Grasshopper and Rhino

1.1.1. Analysis stage

In this stage multiple software are used to evaluate the space visual comfort, the analysis process is shown in Figure 1:

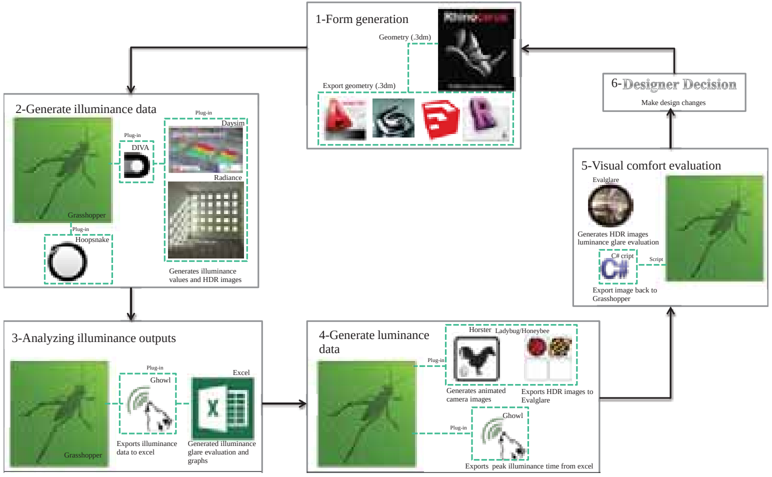


Figure 1: Analysis programs workflow.

1- **Form generation:** the design 3D model input is created in any 3D-modeling software, generated geometry is exported in a (.3dm or .3ds) formats to Rhinoceros 3D modeling software.
2- **Illuminance data simulation:** illuminance data are generated from the inserted 3D model using Grasshopper (GH); a Rhino graphical algorism editor (McNeel & Associates, 2007). DIVA-GH (a Radiance interface) is used to generate illuminance data. Hoopsnake is a GH-plug-in used to loop through different days and hours.
3- **Illuminance analysis:** illuminance data are exported to Excel for analysis using Ghowl, a GH-plug-in. Illuminance evaluation (UDI and illuminance ratio) and graphical representation of the data is presented in Excel and peak condition(s) is selected.
4- **Luminance simulation:** Ghowl exports the peak condition(s) day(s) and time(s) back to GH. Luminance data are generated through a DIVA-GH visualization simulation to produce an HDR image. An animated camera is placed on the circulation path at the peak point(s) using Horster- GH-plug-in. the HDR image Glare evaluation is done through Ladybug/Honeybee;a GH-plug-in that interfaces with Evalglare; image glare evaluation software.
5- **Visual Comfort Evaluation:** Evalglare evaluates the images luminance (DGP and Max glare points); final visual comfort condition is represented to the designer.
6- **Designer Decision:** based on the case evaluation the designer makes the decision on modifications to the initial design and re-run the evaluation.

1.1.2. Design evaluation stage

The research literature review showed that no previous index was intended for visual comfort evaluation in transitional daylit spaces. Consequently the process of identifying glare conditions required the implementation of multiple luminance and illuminance evaluation metrics with associated threshold level.
The evaluation output includes the following as dependant variables: 1- illuminance based metrics: (illuminance ratio and Useful Daylight Illuminance) and 2- luminance based metrics: (DGP, maximum glare points) as shown in Table 2.

Table 2: Luminance and illuminance metrics.

	Description	Threshold/guidelines
1-Illuminance based metrics	They are based on the simulation illuminance value at each stationary point on the path.	
Useful daylight illuminance (UDI)	insures that all the simulation points illuminance are within the useful limits (Nabil & Mardaljevic, 2005).	5<UDI<20 FC at least 50% of the time.
Illuminance ratio	The illuminance value for each simulation point was compared with its neighbors and the ratio was evaluated based on the thresholds.	Based on the examined space illuminance ratio of 5:1
2-Luminance based metrics	They are based on the visualization images. A simulated camera “looking straight forward” was placed in the 3D-model at the points and times exceeding illuminance thresholds.	
Daylight Glare Probability (DGP)	DGP is based on the vertical eye illuminance as well as the glare source luminance (Harvard, 2006).	Average perceptible effect (0.38). Points exceeding the threshold should not exceed 10% of the time.
Maximum glare points	Points brightness exceeding (2x) the average brightness of the image. (Larson et al., 1998; REA, 2010)	Points exceeding the threshold should not exceed 10% of the time.

Based on the evaluation findings, a visual comfort condition (intolerable, perceptible or subtle) was presented.

The proposed tool represents a decision support tool: it does not aim to make decisions for the designer. Possible design alterations are endless; consequently the design modification decision is left to the designer as demonstrated in the framework overview in Figure 2.

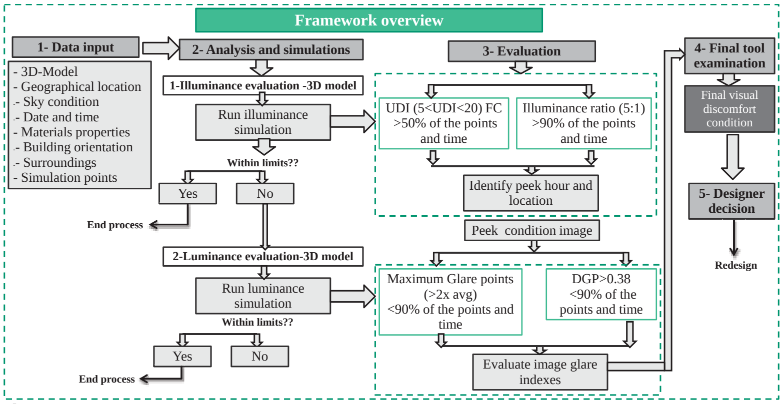


Figure 2: Framework overview

1.2. PHASE2: CASE STUDY

Visual comfort of a passageway “transitional space” between multiple gallery spaces was examined in Freer Gallery of Art, one of the Smithsonian’s museums of Asian art, located in Washington D.C, USA. The museum galleries have a long history of acclaimed exhibitions and present some of the most important holdings of Asian art in the world. The building was selected for many reasons: 1- it carries different artifacts or exhibits sensitivities varying from very sensitive artifacts requiring minimal rather stable light exposure to non sensitive outdoor exhibits 2-daylighting is the main lighting source in the building, and 3- a corridor transitional spaces surrounds the central court and connects the different galleries, Figure 3.

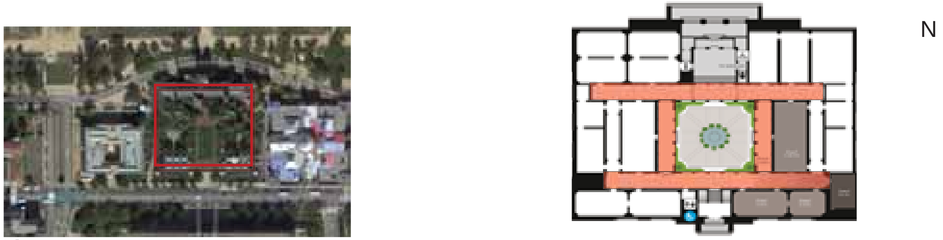
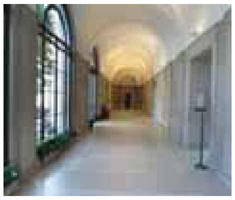


Figure 3: Freer Gallery Museum location and plan circulation

The museum space can be subdivided in terms of illuminance into 6 zones as shown in Figure 4: zone1: The Peacock Room: darkest room (0.8-3FC), zone2 and zone3 oil paintings (2-10 FC), zone4: transitional space (3-30 FC), zone5: old Chinese writings and books (1.2-4.5 FC), and zone6: outdoor court (70-400 FC),

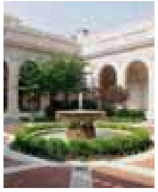
Zone1

Zone 2 and 3



Zone 4

Zone 5



Zone 6

Figure 4: Freer gallery examined lighting zones

1.3. Case study data input

A simplified 3D-model for the museum building was examined for visual comfort, detailed data input are explained in Table 3.

Table 3: Case study data input

Variable	Examined Case properties
Geographical location	The selected museum location weather (Washington DC) was used for this case.
Sky condition	Clear sky without sun
Date and time (mm dd hr):	A one hour interval was simulated for selected days of (December 21-June 21- march 21).
Materials properties	Custom materials are applied based on the in-situ luminance meter measurements.
Building orientation	The 3D model was rotated to match Rhino default orientation
Building geometry (3D-model)	A 3-D model for the examined building was generated and exported to Rhino 3D modeling software.
Surroundings	The building is located on a semi-flat site, no adjacent buildings or significant vegetations.
Simulation points	Points are positioned in the 3D-model circulation corridor- Figure 5.

From the researcher's observation of the visitors' circulation in the museum, one main circulation path was examined: the passageway connecting the Peackock Room (zone1) and the outdoor court (zone6). A circulation polyline was placed in the 3D-model. Simulation points are placed as shown in Figure 5. horizontally at (5.6ft) and vertically at equal (7.7ft) segments. First illuminance simulations were conducted for each point followed by image luminance simulation for the selected peak point(s).

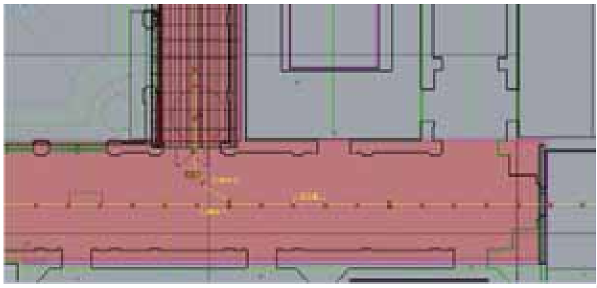


Figure 5 (a): Stationary illuminance points (floor plan).

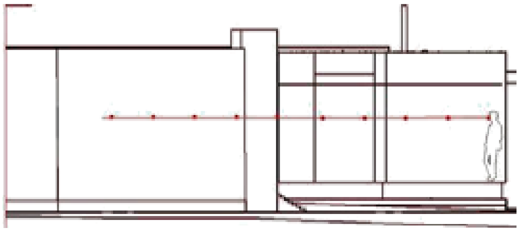


Figure 5 (b): Stationary illuminance points (section).

1.4. Analysis and simulation

Illuminance evaluation: Illuminance evaluation concluded that useful daylight illuminance= 81%, Figure 6(a) and the peak illuminance ratio is found between points in zone4 (corridor-point 5) and the ones in zone6 (outdoor court-point6) = 1:16 as shown in Figure 6(b). Consequently further luminance evaluations were needed at the discomfort point.

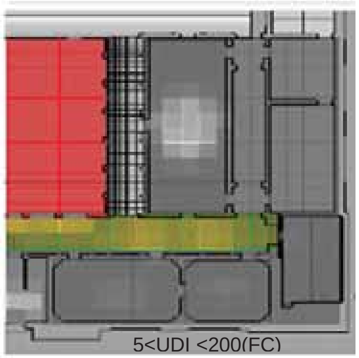


Figure 6 (a): UDI distribution

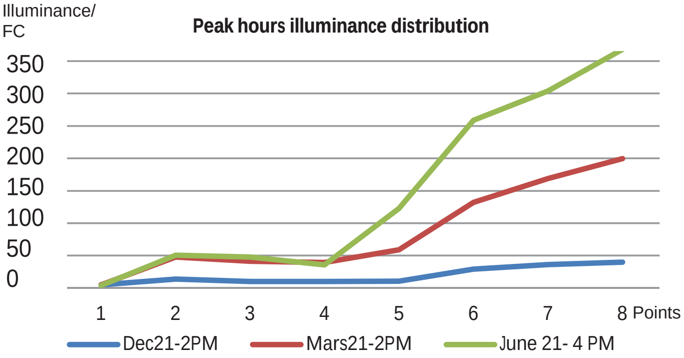


Figure 6 (b): Peak times illuminance distribution

Luminance evaluation: Image luminance analysis is the second stage of visual comfort evaluation.
1) A camera with similar human eye lens properties was positioned at the peak stationary point, Figure 7(a)
2) An HDR visualization image was simulated using DIVA, Figure 7(b)
3) Evalglare was used on the rendered images to obtain DGP and maximum glare points Figure 7(c).

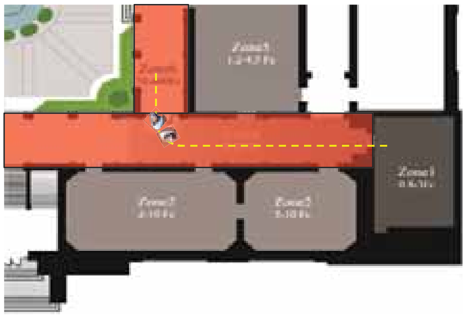


Figure 7(a): Peak point camera

Figure 7 (b): Fisheye image and brightness heatmap

-DGP=0.21
-%glare points in image=12.6%

Figure 7 (c): Evalglare evaluation

1.5. Case evaluation stage and examination

Simulated images were evaluated through the examination of the maximum glare points and DGP indexes. Luminance evaluation concluded that the percentage of image glare points in the visual field was12.6% (perceptible) and DGP=0.21(within comfort zone- imperceptible).

1.6. Designer decision stage

Grasshopper software was initially used in the process for its ability to run parametric design; based on the final design evaluation the designer can make better informed decisions on design adjustments. Design modifications are endless and only the designer can decide on design adjustments. The designer can apply parametric analysis on interior or exterior geometry, in addition to materials properties adjustment.

2.0. SUMMARY AND CONCLUSION

Visual comfort study is a significant matter when designing spaces. The goal of this research is to improve design decision making through the representation of daylighting visual discomfort. A design assistance framework was proposed to evaluate a given space from the visual comfort perspective. The case study application examined a transitional daylit space in a museum space where outcomes showed tool adequacy to evaluate visual comfort. The research outcomes are expected to provide designers and decision makers with an approach for designing and re-imagining spaces to improve visual comfort and space quality.

3.0. FUTURE WORK

For the framework evaluation to generate more trusted results some future developments need to be considered including multiple lighting directions, eye directions, visual discomfort in occupants with visual impairments, a database of electrical lighting to be considered in the simulations, the study of the effect of thermal and mood comfort on visual comfort. As a future research step the framework needs to be evaluated by a group of designers to investigate its potentials to inform the design process. In addition a group of daylighting professionals need to examine to tool effectiveness in terms of glare and visual discomfort evaluation. The framework is intended to be developed into a tool that informs the designer with visual discomfort, especially in the early stages of the design process.

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