A Framework to Improve Designers' Understanding of the Quantitative Results of Daylight Analysis

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ABSTRACT

Decision-making in architectural design is a complex process that includes factors such as aesthetics, environmental, and user needs (Gercek and Arsan, 2019). Utilizing computational simulation tools is one way to gather quantitative data efficiently to help architects in this process (Reinhart and Fitz, 2006). Recent literature on decision-making in architectural design states that it is significant for architects to create a link between their professional experience gained from previous work and knowledge provided from simulation tools (Gercek and Arsan, 2019). Daylight simulation tools are regularly accepted in the market, since it is difficult to evaluate the quantity of daylight in a space through a simple equation (Reinhart and Fitz, 2006). Whether the daylight simulation is done in-house or by a consultant, it is imperative for architects to have empirical knowledge about how the numerical results relate to the user experience.

In this article, a set of methods is proposed to improve designers' understanding of daylight simulation results. The study has been conducted in July and August of 2019. The methods used in this study are survey, daylight simulation, and daylight measurement via environmental monitoring. The participants who are designer/occupants in a design firm in Raleigh, North Carolina, USA, participate in an online survey asking about their productivity and visual comfort in the space. Daylight simulation analyzes the illuminance levels in the office space with Ladybug and Honeybee - plug-ins of Rhino Grasshopper. Furthermore, the actual illuminance in the space is measured by Omron 2JCIE-BL01 sensors in certain locations for additional empirical evidence. A correlational analysis is conducted between the questions of the survey, its results shows that there is no statistically significant correlation between visual comfort and employees' perception of productivity in the summer. Also, the data gained from the sensors and survey show that the daylight is not equally distributed across the office, ranging from 100-1500 lux. Ultimately, by sharing the findings with the participants in the meeting, while conducting the realtime daylight simulation, they can relate results to their own experience in space. It helps them improving their design knowledge and process for meaningfully integrating daylight in their design.

INTRODUCTION

The decision making process of designing buildings is complex to meet the needs of stakeholders and the requirements of the project. (Gercek and Arsan, 2019). Simulation software have started to being used by architects in the design process since 1990s (Reinhart and Fitz, 2006). United Nations' statistics (2017) show the growth in urbanism, and it shows that by 2030, 60% of the world's population will live in urban areas. Most people in urban areas will spend their time in office buildings (ASHRAE, 1993). The main cost of operating these buildings is operational with 90% of costs over the lifetime of the building being spent on staff (Clements-Croome, 2000; World Green Building Council, 2014). Romm and Browning (1998) state that one percent increase in the productivity of office workers can be equal to the company's annual energy cost. By creating comfortable conditions in the office spaces, employees will be more productive and healthier, and be less stressed (Konstantzos and Tzempelikos, 2017; Heschong, 2003; Aries et al., 2015). Human comfort in the environment caused by the contribution of four comfort conditions which are thermal, visual, acoustics and indoor air quality (ASHRAE Guideline 10P, 2014). Creating a comfortable visual space for occupants considers as the main goal in designing working and living spaces (Konstantzos and Tzempelikos, 2017).

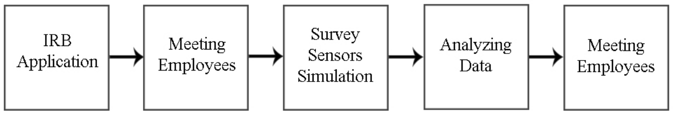


Figure 1. Research Design Diagram. Image credit: Author.

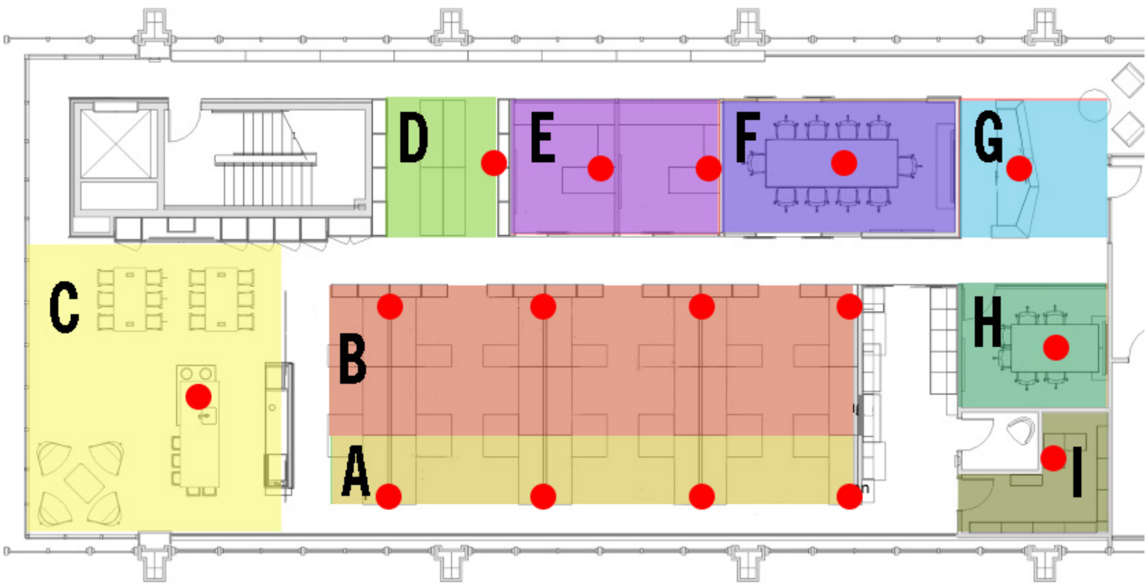
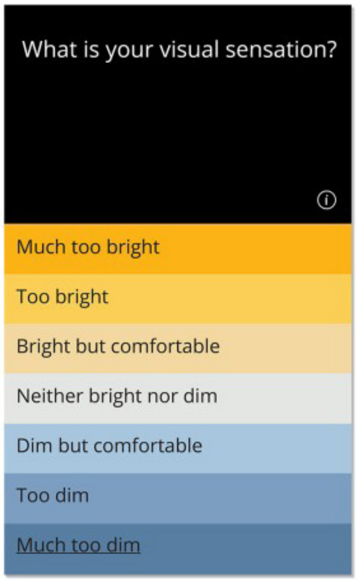
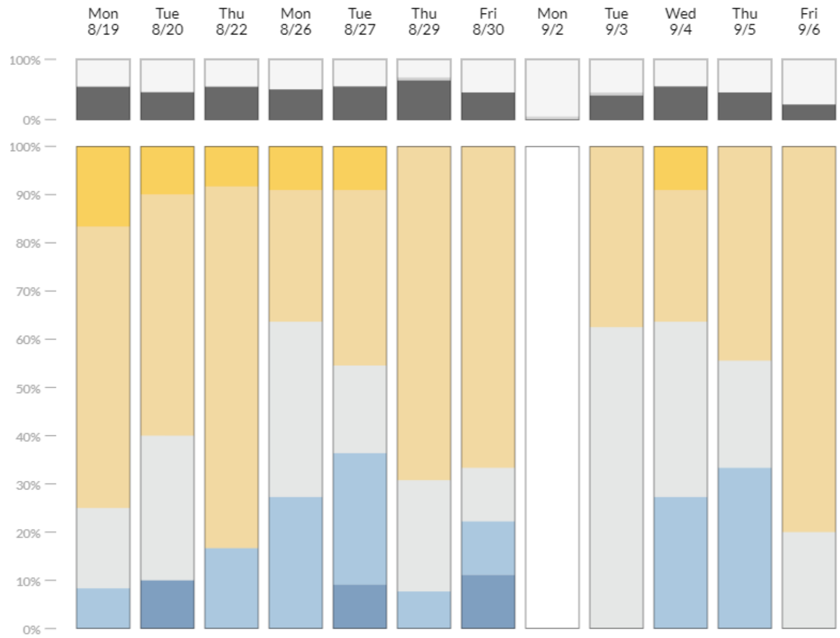


Figure 2: Zones and the locations of sensors. Image credit: Author.

ZONE NAME	DAYLIGHT EXPOSURE	ZONE TYPE	# OF SENSORS IN THE ZONE	HEIGHT OF SENSOR FROM THE FLOOR
A	DIRECT SOUTH	OPEN OFFICE	4	3
B	INDIRECT NORTH	OPEN OFFICE	4	3
C	DIRECT SOUTH AND WEST	DESIGN LAB	1	7
D	DIRECT NORTH	MATERIAL LIBRARY	1	5.5
E	DIRECT NORTH	CLOSE OFFICE	2	3
F	DIRECT NORTH	CONFERENCE ROOM	1	6
G	DIRECT NORTH	RECEPTION	1	2.5
H	INDIRECT NORTH	CONFERENCE ROOM	1	2.5
I	NO DAYLIGHT	SERVER ROOM	1	4.5

Table 1. Zone properties in the office. credit: Author.





(Left) Figure 3: Visual comfort survey.; (Right) Figure 4: Visual comfort survey responses. Image credit: KT Innovations: ROAST.

In their recent literature review about decision making in architectural design, Gercek and Arsan (2019) state that each architect or designer acquires insight from professional experience gained from his or her previous experiences, either in previous projects or personal experience of a space. Among the building simulation software types, daylight simulation tools have a high rate of acceptance and usage in the architecture market. One of the reasons is that it is hard to calculate the quantity of daylight through a simple equation (Reinhart and Fitz, 2006).

In many design firms that perform daylight simulation, members of the building performance analysis group are not core members of the design team, as they are serving many projects. Analysts optimize the performance and interpret results, but many architects don't have experience with computational design software tools, or lack expertise in interpreting daylight simulation quantitative data and how these levels (i.e. 200 lux) contribute to the spatial experience. The main purpose of this study is to increase this knowledge among architects, interior designers and the collective design team. Thus, they will be able to interpret the quantitative results of the daylight analysis data and will respond to the output, incorporate the daylight results to improve design.

METHODOLOGY

The participants of this project and study are 18 full-time employees in an architecture firm in Raleigh, North Carolina, USA. The office is on the third floor of an eight-story building in downtown Raleigh. The research design diagram is shown in Figure 1. The study is conducted between August 19th to September 6th, 2019. For environmental monitoring, the office was divided into nine zones (Figure 2), and the location of sensors are shown by red circles in the Figure 2. Omron 2JCIE-BL01 sensors were used in this study. Table 1 shows the properties of each zone, and the height of the sensor in each of these zones. These sensors measure some environmental conditions such as dry bulb temperature, relative humidity, illuminance level, sound level, Pressure, and UV level. The sensors are wireless and connected via bluetooth and physically small (1.9in x 1.5in x 0.6in), so they do not interfere with the employees' everyday tasks.

A confidential online survey was distributed among the participants four times a week (one survey per day) over three consecutive weeks. During the first half of the study, the surveys were sent to participants at 2:30pm and during the second half, at 9:30am. The Roast Survey (Figure 3 & 4), developed by Kieran Timberlake, KT Innovations, was used in this study. In the survey, the participants must choose where they are located in the office within the preceding 20 minutes, clothes, and their activity. Questions aim to capture thermal, visual, acoustics, indoor air quality, and employees' perception about their productivity, as well as the improvements that they have used in their space. The 7-point scale (Figure 3) was used for the comfort questions, and the 5-point scale used for productivity question. This survey plots the data to a visualization method on the floor plan, using a separate graph for each of the questions. It also allows for exporting a .csv file for further analysis, which was exported for visual analysis in Tableau and statistical analysis in SPSS software.

The illuminance level of the office building was analyzed in Honeybee and Ladybug - two plug-ins in Rhino Grasshopper. A meeting was held to share the results with participants, where the real-time analysis/simulation of the office space, sensors and the collective results of the survey were presented so that the designers could relate the data points and synthesize.

Figure 5 (top) the light level of Zone A, (bottom) the light level of Zone B, Image credit: Author

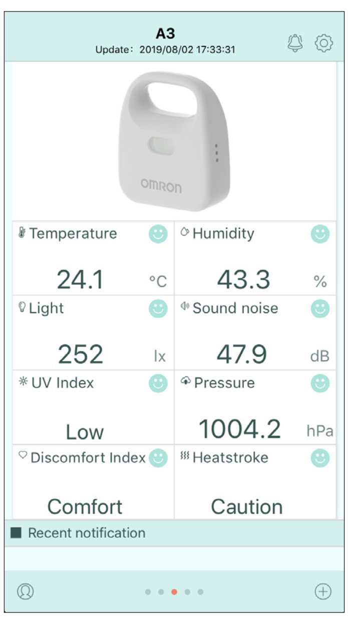


Figure 6 (left) Mobile device interface of the bluetooth wireless sensor, Image credit: Omron

Figure 7 (center) Sensor location on the work station, Image credit: Author

Figure 8 (right) Sensor's presence, signage and size, Image credit: Author

			PRODUCTIVITY VALUE	VISUAL COMFORT VALUE
KENDALL'S TAU-B	PRODUCTIVITY VALUE	CORRELATION COEFFICIENT	1.000	-0.007
		SIG. (2-TAILED)		0.924
		N	123	123
	VISUAL COMFORT VALUE	CORRELATION COEFFICIENT	-0.007	1.000
		SIG. (2-TAILED)	0.924	
		N	123	123

Table 2: Correlation analysis between two questions in the survey (productivity and visual comfort), Image credit: Author

RESULTS

Statistical analysis was conducted in SPSS regarding the correlation between visual comfort and productivity factors in the survey. As it is shown in Table 2, there is no statistically significant relationship between visual comfort and employees' perception of their productivity (p=.924). Figure 3 shows the survey question regarding visual sensation. Figure 4 shows the results of a survey for the question relating to visual comfort. The results show that most people feel bright but comfortable during the period of the study.

The results of the survey also indicate that most of the participants who responded "too dim" or " dim but comfortable" are located on Zones F, G and H. These zones are located on the north side of the building or having indirect north sunlight. Figure 5 shows the results of two sensors: one located in Zone A (direct south daylight), and the other in Zone B (indirect south daylight). The image of one of the sensors in Zone A is shown in the Figure 6. At midday, the lux values in Zone A are very high (more than 1500 lux) which is not healthy for the workplace, while in Zone B, the highest lux value is 100 lux. This shows the unequal distribution of lighting across the space.

Figure 7 and 8 show the results of the building simulation in the meeting day (October 11, 2019) in Honeybee and Ladybug. An hour-meeting was held at the end of the integrate the results of the office daylight simulation, the sensor data, results of the survey and their experience with the design research. The goal of this meeting is to educate participants about the relationship between the results of the building daylight simulation and sensor data with their experience to educate and discuss strategies to increase awareness to optimize future environments. The continuation of this study plans to explore how sharing knowledge impacts the ability to iterate design solutions and progress decision making.

ENDNOTES

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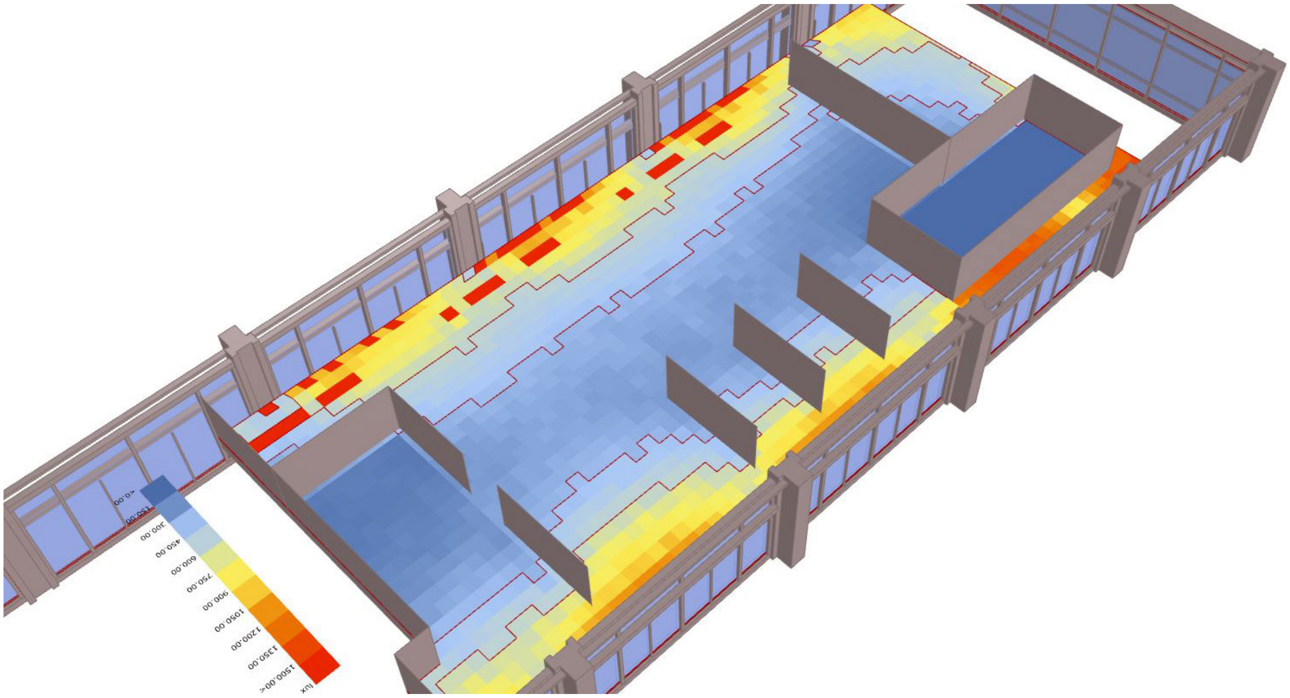

Figure 9: Building Daylight Simulation with Honeybee and Ladybug, Image Credit: Author.

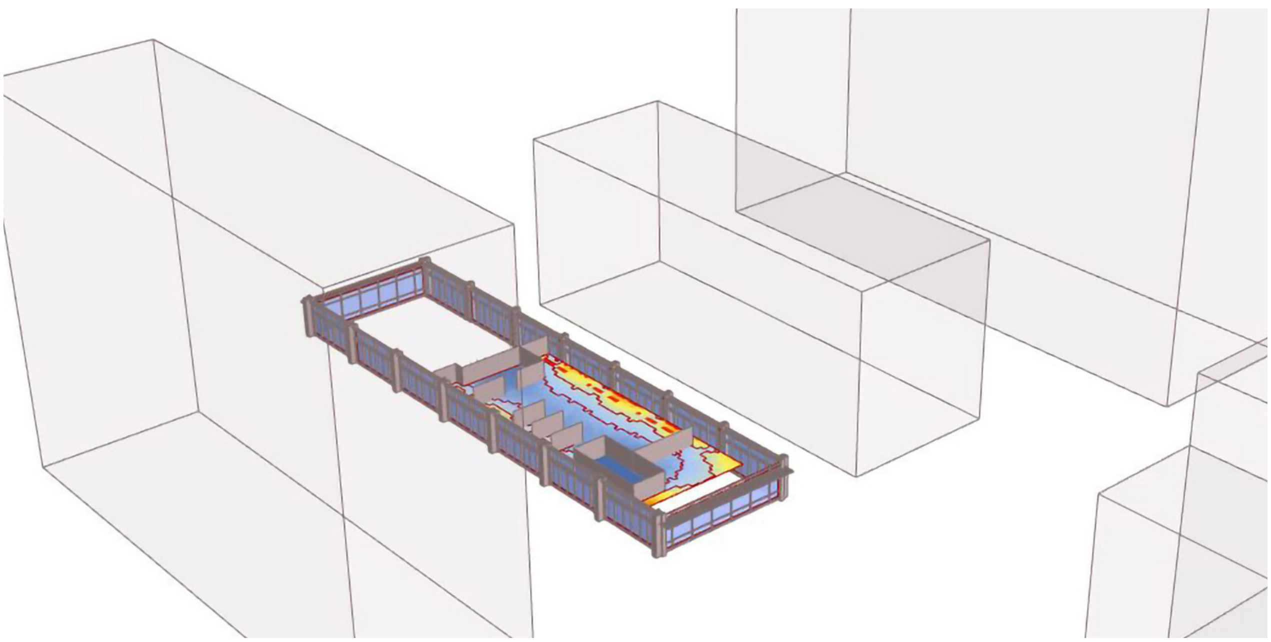

Figure 10: Building Daylight Simulation with Honeybee and Ladybug, Image Credit: Author.