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INTERACTIVE GLARE VISUALIZATION MODEL FOR AN ARCHITECTURAL SPACE

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Abstract

Lighting design and its impact on indoor comfort conditions are an integral part of a good interior design. The impact of lighting in an interior space is manifold, and it involves many sub-components like glare, color, tone, luminance, control, energy efficiency, flexibility, etc. While other aspects of light have been researched and discussed multiple times, this paper discusses the research undertaken to understand glare from an artificial lighting source in an indoor space. The paper discusses a parametric model to convey instantaneous approximate glare level in an interior space to users. We foresee Architects as one of our main end user's and likewise for them it is of utmost importance to know what impact the proposed lighting arrangement and proposed furniture layout will have on the indoor comfort quality. Essentially, the designer would need to know the ramification of the 'discomfort glare' at the early stage of the building design, when he can afford to recommend changes to the design scheme by selecting other potential alternatives for his client. Unfortunately, most of the current lighting analysis tools, offer lighting simulation studies based on rigorous computation and analysis. Evidently this makes it difficult for the designer to quickly analyze and interpret the interior discomfort glare level inflicted due to the design of the interior space. Intending to address this problem, this paper, explains a novel approach to approximate interior glare data. Furthermore, we visualize this data, as a color coded overlay on the 3d model of the interior space, assisting users to understand the implications of their proposed interior design layout. Our focus is to make the analysis and the visualization relatively fluid, fast & computationally scalable. Our system embeds real-time user interaction by varying user inputs and editing the 3d geometry of the space. Additionally, we tested our proposed parametric model on a case study space - A Computer Lab interior layout in our college facility.

Keywords: Parametric glare model, Interior design, Lighting Analysis, Design simulation.

1 INTRODUCTION

Our intent is to develop a relatively fast algorithm which will not only compute glare from an artificial light source in an indoor space but also will visualize the same. As a result, the designer/ architect can use it fluidly at the conceptual/ schematic design stage to quickly validate design proposals. Adding our system to the current workflow would facilitate production of quality interior space by enriching the indoor comfort level. Researching along similar lines, we realized that there are many rendering engines available with sophisticated graphical algorithms, representing an aesthetic aspect of lighting, comprising of indirect illumination, global illumination, ambient occlusion, daylighting, etc. However, there's lack of any tool which can visualize the performance of interior lighting fixtures regarding glare for the comfort of the user almost instantaneously. We developed the strategy, to deliver fast and almost real time results, at the cost of slight precision. Our research venture addresses these issues and presents a solution which can successfully implement such a system for varied design layouts and furniture arrangements.

2 MOTIVATION

Not only is glare an important component of discomfort for occupants both in indoor and outdoor space, but it also has a serious impact on people's psychological and physiologically health. Linewise,

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one of the driving reasons to pursue this research, was to enable Architects design spaces, which do not transcend discomfort due to glare from indoor lighting.

Recent medical and biological study enlightened the fact that light entering human eyes not only have a visual effect but also a significant non-visual biological implication on the human body (Bommel, July 2006). Evidently any space with good lighting design has positive impacts on the human health, well-being and alertness. It also enriches sleep/wake cycles, performance patterns, core body temperature and production of hormones. Certainly, this commands that new rules governing the design of good and healthy light installations are essential. Not only does good lighting arrangement attains expected the level of visual performance, but it also regulates the surrounding spatial appearance. (L. Bellia, October 2011).

Recent discoveries in photobiology are creating a link between lighting, health and well-being. It fosters lighting design, which deals with indoor glare problem by analyzing and processing the luminance pattern, along with providing adequate visual quality to space. Visibility is still an essential aspect of any lighting installation, but good quality of lighting installations are being judged based on other important virtues including quantity and quality of required light for wellbeing, health, interpersonal relationships and aesthetic appeals. (L. Bellia, October 2011).

Light defined as that part of the electromagnetic spectrum (~380–780 nm) that gives rise to a visual sensation. Lighting in buildings, whether through the-the use of daylight or by artificial means, is designed primarily for the visual needs of the occupants and their expected tasks within a given space. Solar radiation, daylight, artificial light has a range of influences on the human. In addition to vision, it controls the circadian rhythm of hormone secretions and body temperature with implications for sleep/wake states, alertness, mood, and behavior. Symptoms of the disruption of these cycles through changes to the natural light/dark cycle can range from temporary jet lag to severe depression. Considering lighting is such an important part of healthy human life, an interior space design endowed with good lighting conditions, adequacy to meet aforementioned human comfort level is at the highest level of importance (Webb, July 2006). Noteworthy to mention that unlike other e-m radiation, light is sensitive to our eyes due to a certain range of wavelengths, and thus we can see it. Light has biological effects like stimulating or relaxing or supporting circadian rhythm, in addition to its more commonly known visual functions like the illumination of workspace conforming to relevant standards. Above all, light has emotional effects, like enriching space quality, creating memorable effects, etc. (The Lighting Handbook, Oct 2013)

3 RELATED WORKS

In the domain of computer graphics and computational geometry, some studies have been successful in analyzing and visualizing interior artificial lighting or glare for the user. Most of them were very precise, but not very fast computationally to allow the end user quickly test his ideas in almost real time and get a near precise feedback in an ad-hoc manner. Consequently, this motivated our research to facilitate architects and interior designers enough information to select appropriate design option. Having said that, we found, related research ventures in this area helped us understand the nature, significance, and the complexity of the problem.

Christoph F Reinhart et al. developed a fully integrated design analysis method that simultaneously considers annual daylight availability, visual comfort and energy use. Their work also explains how their tool could be practically implemented using technologies that were available back then. Their work requires that the information needed to carry out a fully integrated lighting/thermal analysis must be available in building information models namely scene geometry, materiality, thermal zones, program, and schedules (Christoph F Reinhart, 2010). It could be a drawback when the designer does not have an adequately detailed model for the project. Often, during the early stage, designers tend to keep the model light regarding data to test different design alternatives and directions. Eduardo Fernandez et al. proposed a method by providing optimal light source positions as well as optimal shapes for skylight installations in interior architectural models. They facilitated the same by exploiting the scene coherence to compute global illumination using a meta-heuristic technique for optimization. Their method provides a fast and accurate method for inverse lighting that enables designers to browse solutions in short time (Eduardo Fernandez, December 2012).

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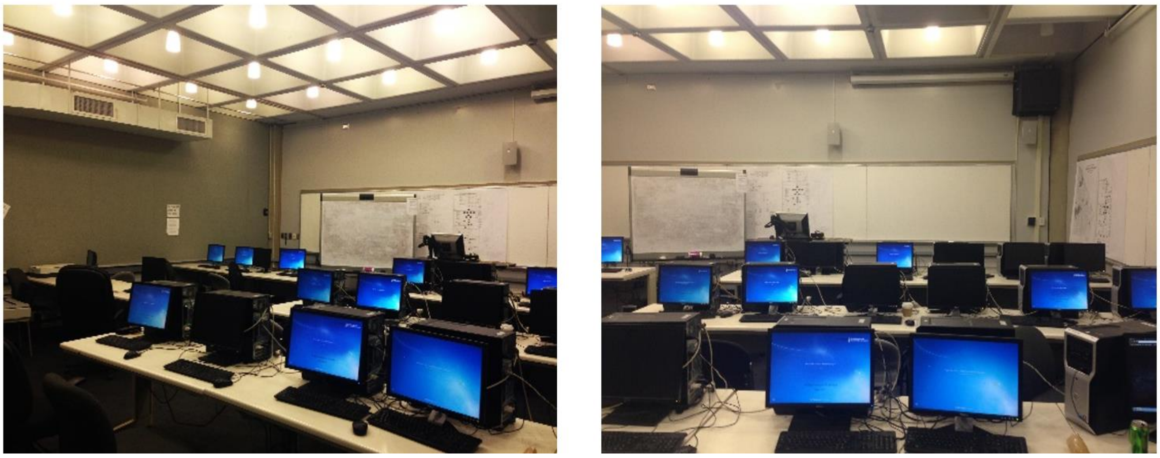

Figure 1. Shows the existing furniture arrangement in the Computer Lab

Hirning et al. conducted an impressive investigation on discomfort glare with 493 surveys collected from five green buildings in Brisbane, Australia. The study consisted of a specially tailored questionnaire to assess potential factors relating to discomfort glare, conducted on full-time employees. The luminous environment of the occupants was captured by the luminance maps extracted from high dynamic range (HDR). Over 49% of occupants reported some discomfort at the time of the survey. It further revealed occupants were more sensitive to glare than any other component of light (Hirning, et al., 2014).

Interior working environment should not impart any visual fatigue to the users. Glare from artificial lighting is one of the causes of that creates visual fatigue. Research by Kim Wonwoo et al. suggested that background luminance is one of the main factors affecting the degree of discomfort glare. They conducted two experiments including visual sensitivity test and glare sensitivity test to investigate the effect. They concluded that the luminance of the immediate background of a source should be considered before the average background luminance (Wonwoo & Yasuko, 2004).

Figure 2. Shows the existing lighting arrangement in the Computer Lab

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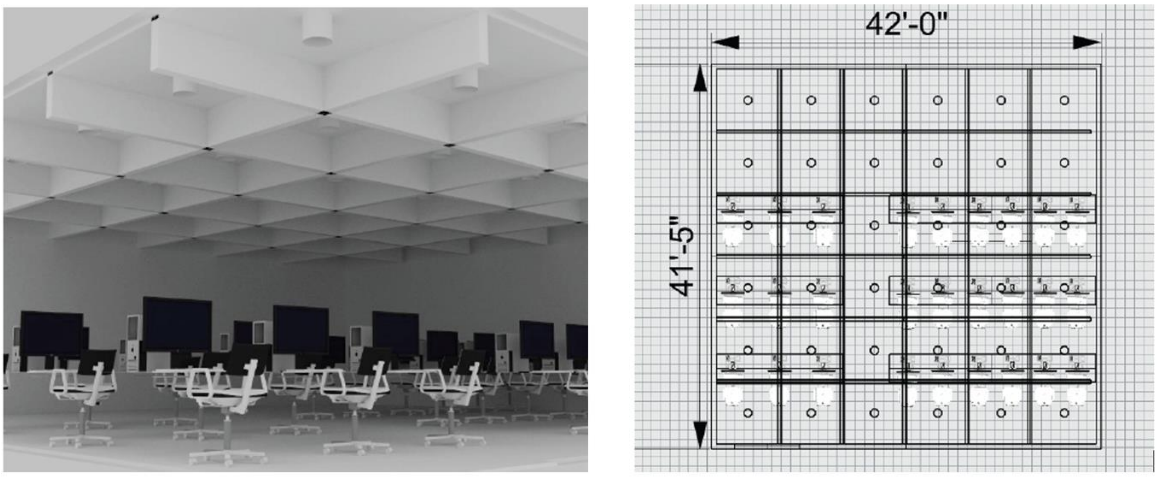

a. b.

Figure 3. a. Shows the 3d model developed in Rhino. b. Shows the layout of the Computer Lab with furniture arrangements.

4 UNDERSTANDING LIGHT AND GLARE

Out of many, most important quality criteria of a proper lighting system are:

a. Glare limitation
b. Correct light color
c. Avoid reflections
d. Uniform brightness distribution
e. Sufficient illumination level
f. Appropriate color rendering
g. Personal control
h. Energy efficiency
i. Daylight integration
j. Light as an interior design element

As we focused on alleviating glare effect, we dived deep into the topic of light and glare to understand their role on each other. Clearly, glare reduces user's performance in the room and inhibits his vision. The paper discusses our work to find zones in interior space with high glare value on reflective surfaces due to interior lighting design. When we mention glare, we mean 'Discomforting Glare,' which is the amount of glare, physically and physiologically harmful and uncomfortable for the user. It creates an irritation or at times pain due to unsuitable distributions of brightness (significantly higher than the luminance to which the visual system is adapted) in the person's field of view. Making it even worse, disability glare (the reduction of visual performance) can accompany discomfort glare (CIE, 1987).

To calculate the amount of glare at a certain point we studied and implemented UGR, unified glare rating (CIE, 1995):

$$\mathbf{UGR = 8 \log_{10} \left([0.25/L_b] \sum [L^2 * w / p^2] \right)}$$

where,

L_b - background luminance (cd m^{-2})
$\sum$ - summation of all of the separate glare sources present
L - source luminance, measured at the observer's eye (cd m^{-2})
w - solid angle of each source at the observer's eye (steradian)
p - 'Guth' position index

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UGR values range from 10 to 30. Higher values represent significant discomfort glare, and lower values represent relatively comfortable glares. Thus, values less than 10 are considered to be in the comfortable glare range. According to our study, for reading, writing, training, meetings and computer-based work UGR values should not exceed 19. (The Lighting Handbook, Oct 2013). Discomfort glare can be further subdivided into the direct glare and reflected glare. Direct glare is that glare which travels directly from the source of the light to the user's eyes. Reflected glare occurs when glare is reflected from any reflective surface, upon which light strikes from its source. Direct glare is mainly caused by direct observation of high luminance in the visual environment of the observer. Reflected glare is caused by the reflection of light from a surface (Mark S. Sanders, 1993).

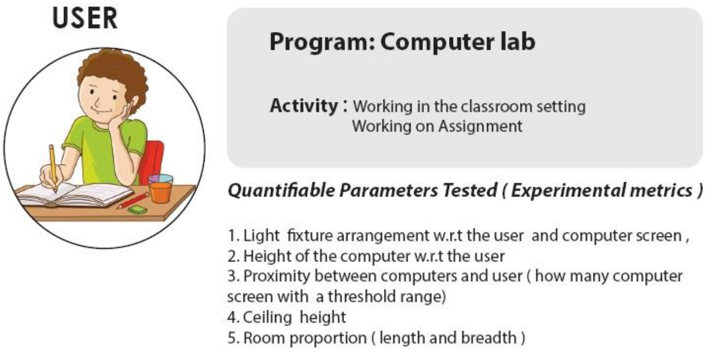

Figure 4. Persona development of a sample user, quantifying the metrics to be analyzed

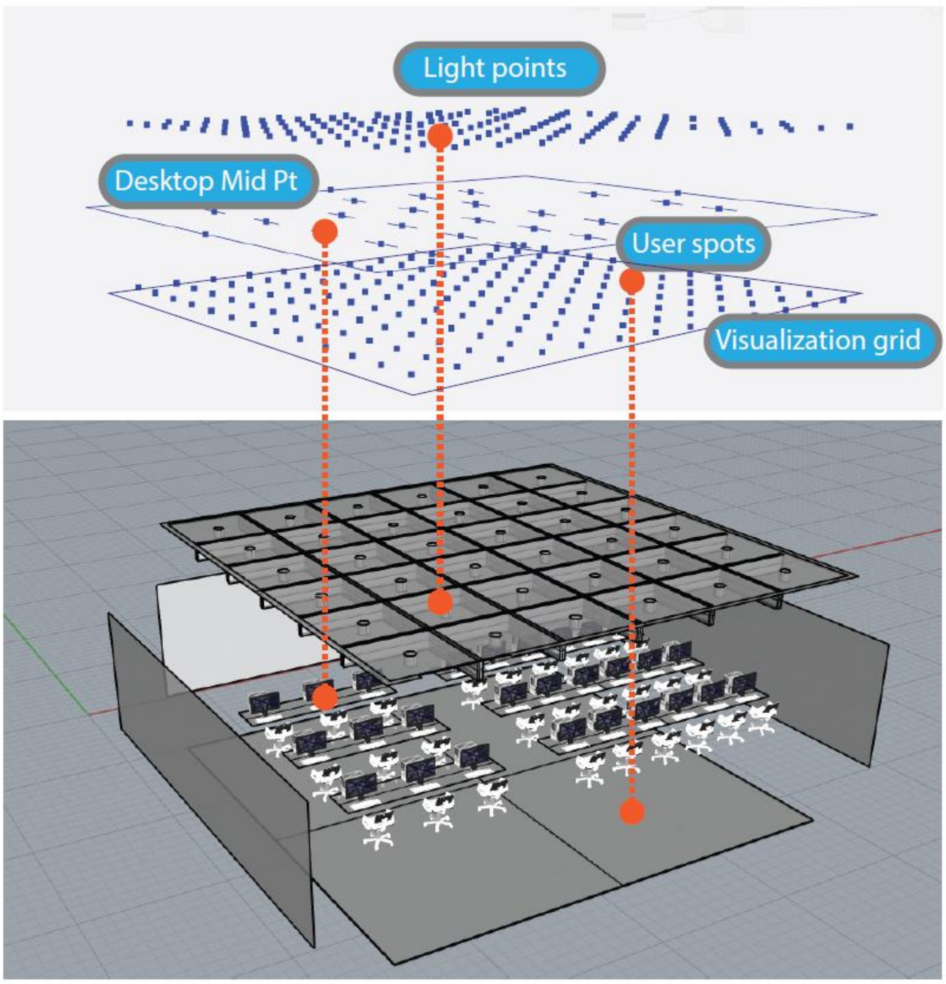

Figure 5. Shows the point grid arrangement of pixel space, user & lighting fixtures. Also shows the 3D Model of the interior space

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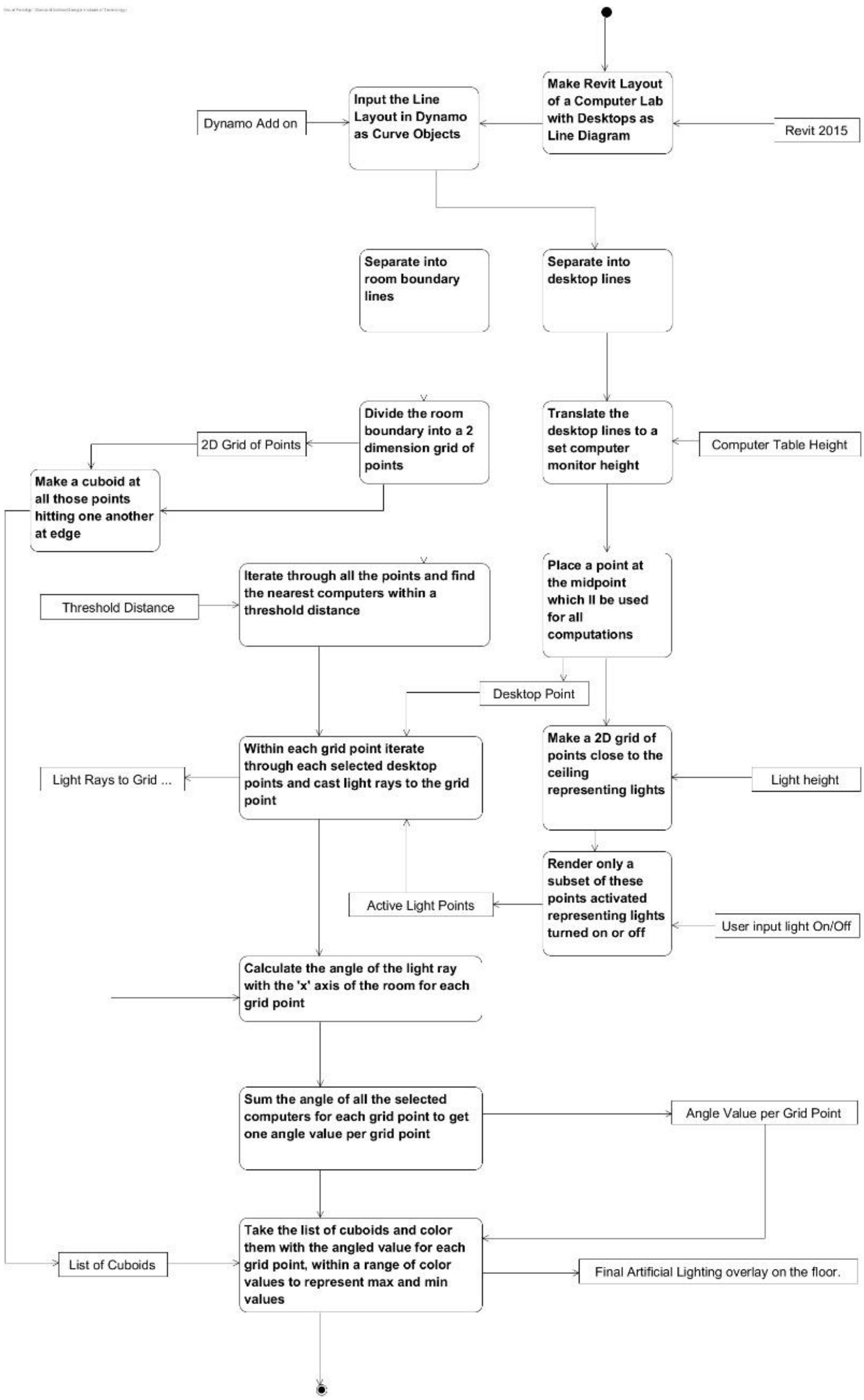

Figure 6. Flow chart describing the work flow process to build the parametric model.

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5 PROCESS AND METHODOLOGY

Implementation details of our system is outlined below:

5.1 Test Space

To test our case we studied the glare effect from artificial lights at the computer lab of Georgia Institute of Technology's College of Architecture at Atlanta, USA. It's a room 42 feet by 42 feet (approx.) in length and breadth with a clear height of 12 feet (approx.). There's no direct daylight access, as there's no external window looking outside. The room equipped with around 20 desktop workstations arranged in a grid-like fashion as shown in Figure 1. There is a presenter's standing space at the front of a projector screen facing the desktop computers. Under the false ceiling, the interior lighting fixtures are hung down as shown in Figure 2. It is noteworthy to add that these light fixtures also follow, grid-like arrangement. Before developing the algorithm, we developed a detailed 3d model of the Lab space to understand its geometry and internal arrangement, just like a typical architect would do while designing the interior room layout. The 3d model was developed partly in Rhino (NURBS-based 3D modeling program) and partly in Revit leveraging the building information modeling workflow in practice to help layout furniture as shown in Figure 3a. For the parametric modeling of the lighting analysis, we used Autodesk's Dynamo Visual Programming tool. The whole setup rendered a very powerful framework to implement and test our glare visualization algorithm. We developed the first proof of concept in Python, embedded in Dynamo as custom nodes, which leverages its pre-built objects and nodes. Work is underway to translate and implement the same algorithm in C# programming language to develop a Lighting analysis library for Dynamo.

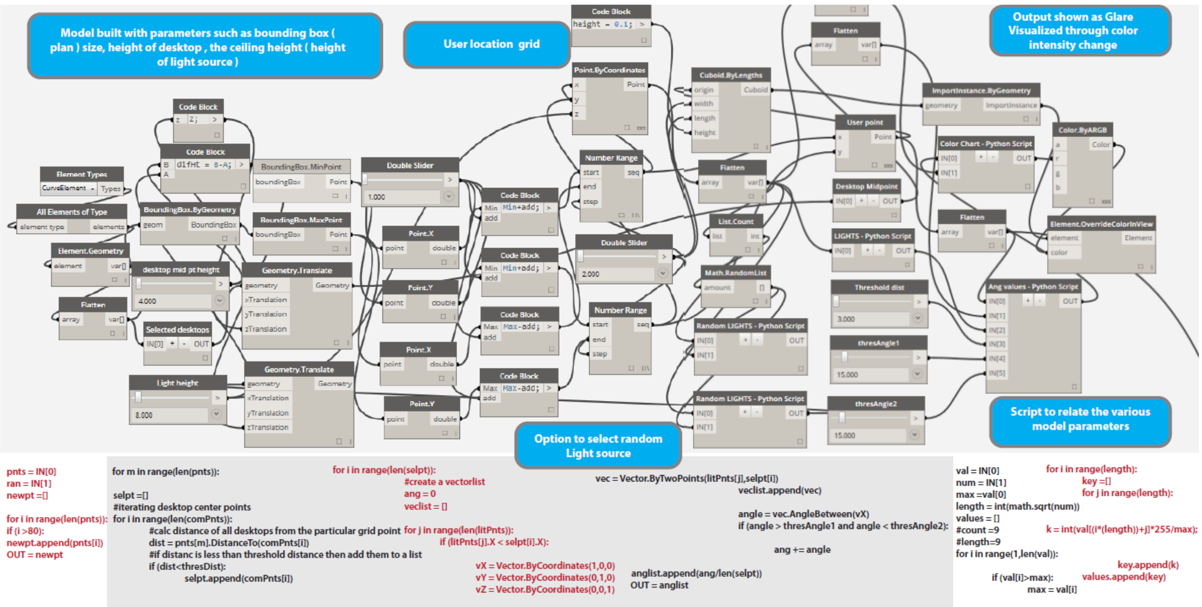

Figure 7. Shows the Dynamo script, having custom nodes written in Python

5.2 Computational Model in Revit

We envisaged that designers shall use our parametric model in real time while designing spaces and interior layouts. Considering Revit as a relatively powerful 3d BIM tool having unprecedented popularity in the realm of building design, our parametric model fits very well with the current workflow. We conceptualized that our users would make a very basic layout (internal space planning and furniture layout) in Revit as shown in Figure 3b, represented as simple line elements. As aforementioned, for our case, the model is the computer lab space, with a set of desktop machines and lighting fixtures arranged in a regular orthogonal grid. The model is kept very light having a basic line drawing in Revit, containing two important elements.

1. An outer periphery representing room boundary and its dimension
2. An internal furniture layout represented by simple lines.

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For the test case, we represent the desktop machines as simple lines (whose length depict the width of the desktop monitor.

5.3 Computational Model in Dynamo

Next, we open Dynamo (from Revit) and import the layout designed in Revit as Line objects. Our script (Refer Figure 7) uses Python to build custom nodes in Dynamo to separate the input line lists into two separate lists

1. List of Lines representing room boundary.

2. List of Lines representing desktop monitors (in general it can be any furniture for any generic case).

First, we handle the list of lines representing the room boundaries. We make a bounding box, which represents the room itself. We make a 2D grid of points inside the bounding box. We take the corner points of the bounding box and use its coordinates as the limiting factor for the point list formed inside. They are used as the maximum and minimum values of the x,y,z coordinates for the point lists. Also, the points near the edges of the room boundary, are offset a bit inside so as to help compute the glare value later on in the script. We use each of these points to form a cuboid whose length and breadth equals half of the distance between the neighboring points and the selected point. The height of the cuboid is kept at the 2-inch dimension. Essentially these cuboids would behave as pixels over which the glare level can be mapped or visualized. We can programmatically change the resolution of the pixels by changing the number of points (in x and y directions) inside the room boundary.

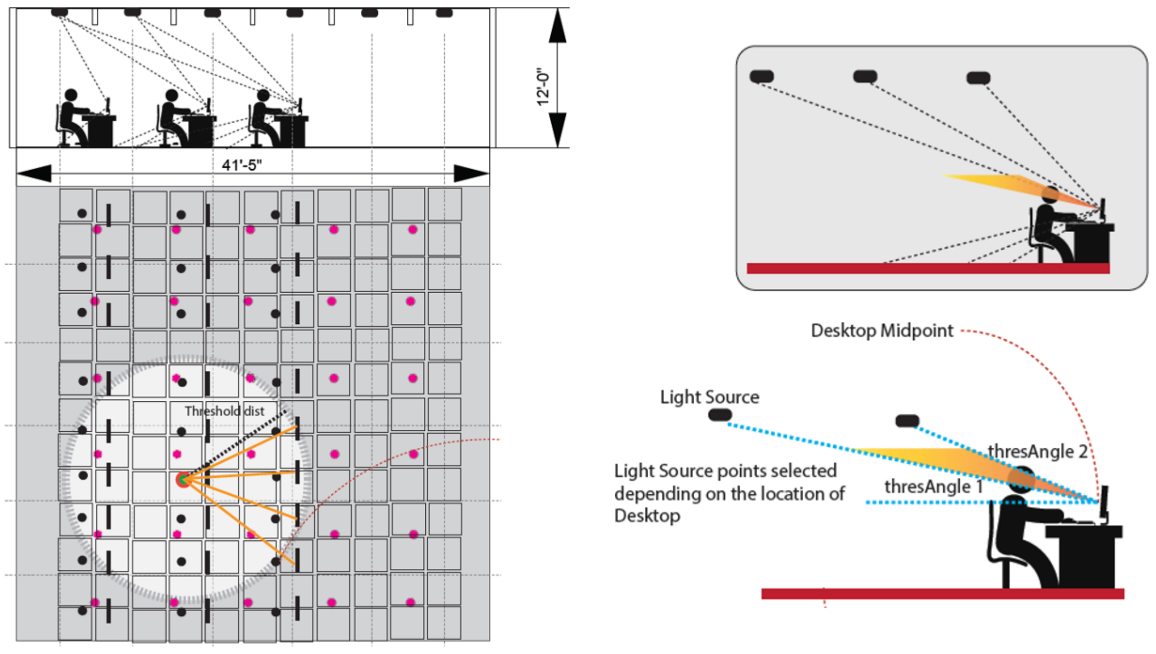

Figure 8. a. Detailed floor layout with room section elaborating the furniture arrangement with the lighting plan. Pink dots represent the lights while black dots represent the user. b. Schematic sections explaining the lighting computations studied to conduct the glare calculation for the user.

5.4 Points & Lines for Computation

To represent the desktop monitor (or any input furniture element which can affect or get affected from or by glare) in our computational space, we store lines representing desktop monitors in a separate node as a python list. Making the system interactive, we allow the users to input the desired height of the desktop monitors, which they can change later on to understand the effect of glare. Based on the input we translate the desktop monitor line object at that level. Other indoor furniture related user inputs are taken including the desk height, varying which the user can test and compare the influence of glare at the different height the monitor is placed. Next, we find its mid-point, used to compute all the computations with the light source. Our idea is to find the level of glare at each pixel space in the room. The glare would be affected by the neighboring desktop computers around each pixel space

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(cuboids placed at each grid points as mentioned before). We enable another level of user interactivity by allowing the user to feed in the minimum threshold distance from each pixel space as shown in Figure 8a. This threshold distance shall determine how many desktop computers shall be accounted for while deriving the glare value. Likewise, in Dynamo Python script, the program iterates through all the desktop machine (represented as a line) and calculates their distance from the light source, It makes a new list of selected desktop machines which are below the threshold distance. These desktop machines shall be used for computing the said glare.

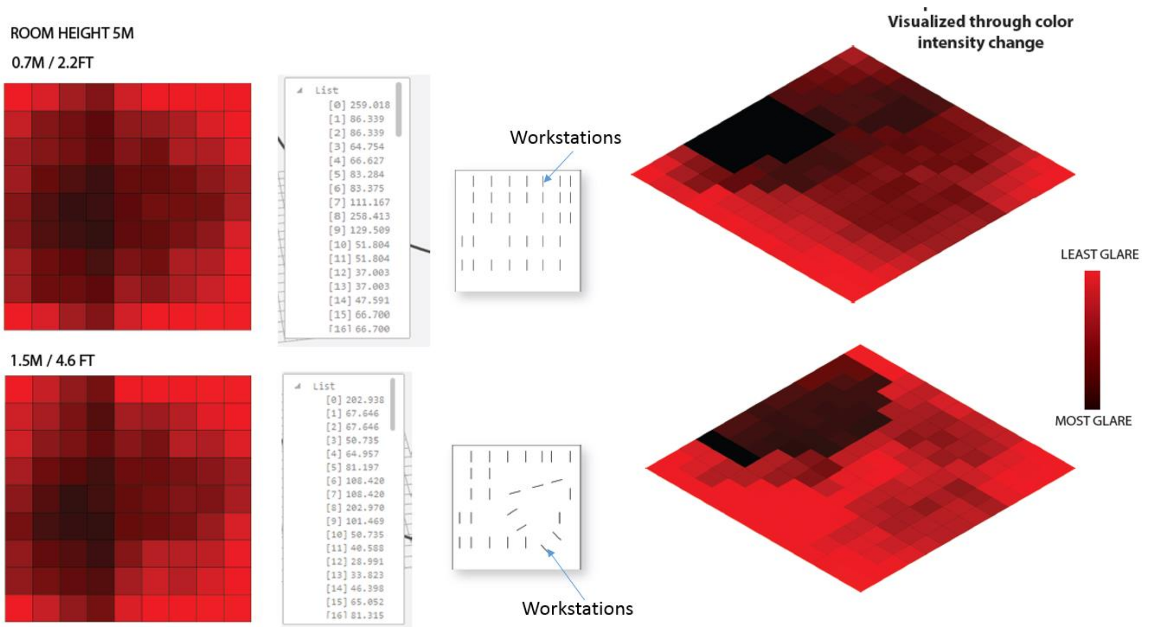

Figure 9. a. Shows the information visualization of room glare at each pixel space mapped over the floor. Also shows, the interior furniture layout represented as simple line elements.

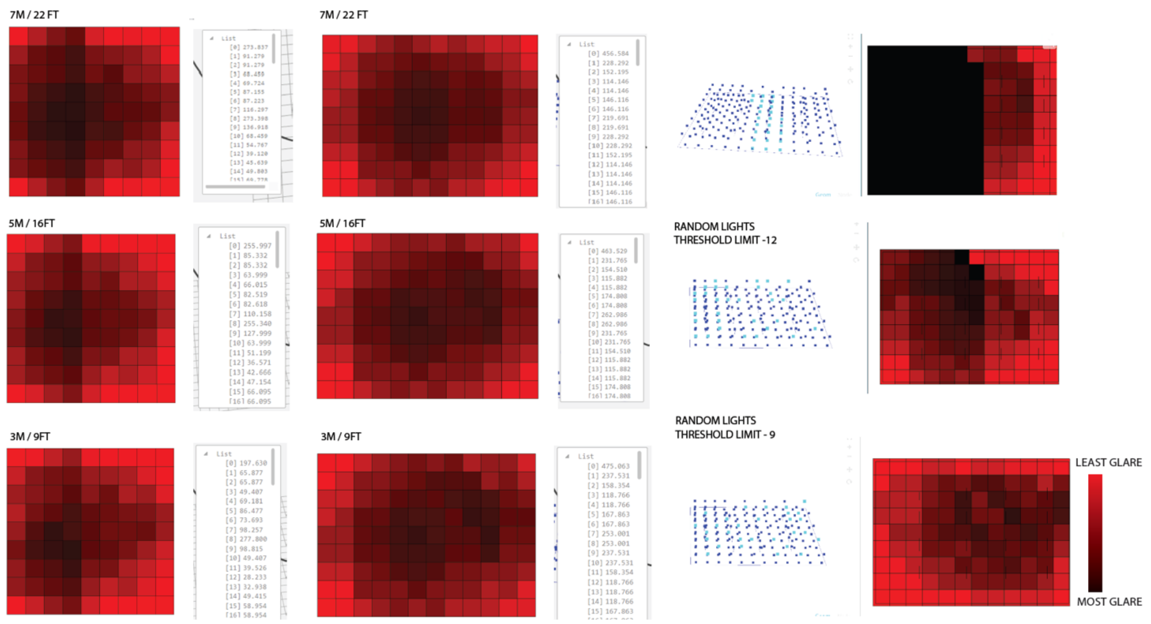

Figure 9. b. Shows the impact of glare at different room heights with the same layout. It also shows the lighting configurations tested. Dark blue points show lights which are disabled while cyan colored points show enabled lights.

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5.5 Lighting Elements

We make another 2d grid of points inside the room boundary in a similar way as the one we made before to build our pixel space on the floor. Though these points are not placed on the ground, they are set at the height of the light fixture level, representing the lights in the computer lab. The height parameter is input by the user adding another level of interactivity for the user. By varying the height of the light, the parametric model can be used to test and compare the impact of glare on the user while placing the light fixtures at varying heights. The light points have two states enabled or disabled. Out of all the points, only those light points with enabled status shall be used for shooting light rays around the room for making glare computations as shown in Figure 9a and 9b. The parametric model includes three different kinds of lighting arrangements. One of them is regular grid-like while the other one is the hexagonal arrangement. The third configuration is the random placement of the lights over the ceiling. The list is extendable by adding custom light arrangement enabling added leverage and flexibility to the designer to test new design ideas and directions. Besides, each light point is accompanied by a rectangle of size 3inch by 3inch representing the light fixture surface. It is used to compute direct glare angles.

5.6 Glare Computation

At this point for each pixel space, we have a list of selected desktop machines and a list of the enabled light source as point objects close to the false ceiling. We compute two kinds of glare as explained below:

5.6.1 Direct Glare

It is the light cast directly on the eyes from the light source. To compute direct glare, we record the angle the light fixture (rectangle object) makes with the Pixel space point location. It's as if trying to compute how much would be the glare at that pixel space if a user is standing at that point. We also record the distance (position index in UGR formula) from the light source to the pixel space point.

5.6.2 Reflected Glare

It is light reflected off of the desktop screen into user's eyes. To compute the reflected glare at that particular pixel space, we iterate over all the selected desktop machines. For each machine, we pick only those lights whose rays will hit the desktop screens from the side facing them as shown in Figure 10. A ray is cast from each of the selected light source points to the midpoint of the desktop machine line object. Also, the distance from the selected desktop machine midpoint to the pixel space point is recorded. Both of these values, the angle of the reflected light and the distance of the reflected light to the pixel space point is needed to calculate the UGR value.

5.6.3 Computing UGR value.

For each pixel space, the UGR value is summed up for each selected desktop machine for all light objects casting light rays on its surface. Further, the UGR values are summed up for all the selected desktop machines allowing one UGR value for each pixel space. Clearly the angle 'w' computed and position index 'p' retrieved from these computations are two key components in computing glare value (by UGR formulae as shown above). Once the UGR values are computed for each pixel space, then they are mapped to the pixel space by a selected color encoding. The list of UGR values obtained for all pixel space gives us the maximum and minimum UGR levels for every pixel space. The color values set for mapping are then interpolated between these maximum and minimum values. As we built the pixel space as a list of cubes able to be overlaid with color and visualized in Dynamo.

6 RESULT AND OUTPUT

Figure 10 shows some of the output results obtained from our parametric model. Different type of lighting configurations resulted in the different visualization of glare level at each pixel space in the computer lab. The color map used represents glare level from the maximum value (darker shade of red) to the minimum value (lighter shade of red.). The regular arrangement of desktop machines was compared with irregularly placed desktop machines in the room. The results varied when the users changed the threshold distance for neighboring desktop machine or when the user changed the lighting configuration or the height of the desktop machine. Another user input which changed the result of the visualization was the height parameter of the light fixtures. Clearly, the way the setup of

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the parametric model is framed, it is built to handle any generic case, with any interior design scheme, furniture layout, room dimensions, and lighting fixtures. Even though the result obtained is an approximation of industry standard glare computation, the primary intent of this venture was to significantly speed up glare computation and visualization by employing fast and scalable visualization algorithm at the cost of some level of precision. It allows the end user the liberty to validate their design layout quickly to make an informed decision. The computation time is controllable by the end user up to a certain extent by controlling the dimension of each pixel unit. Higher pixel resolution took little more time but unquestionably yielded more precise results. The average time for average resolution pixel space model (81 cuboids) for 'the computer lab' test case took around 20-25 seconds. Higher resolution model (225 cuboids) generated glare resolution visualization at around 45-50 seconds per visualization.

7 CONCLUSION

This attempt to visualize near precise real time glare data was successful, and it did provide us quick and robust information visualization of glare data from artificial lighting overlaid on the 3d model of the architectural space. Throughout the process, our main intent was to have the system assist the architect/ designer to select, validate and improve their existing design space. Providing democratized access to rapid interior glare visualization, the said parametric model also emphasizes the impact of lighting design on indoor comfort level and spatial quality, which at times gets unnoticed or unsolved. In future, we are working towards including daylight along with artificial interior lighting to gauge the level of glare in the space. This functionality would render the system more useful for designers making it a more realistic visualization of the impact of the interior furniture layout on lighting design and vice versa. Interactivity was one of the key components and drivers of the visualization model. Certainly ability to set furniture layout, room dimensions, custom floor layouts along with the ability to customize lighting arrangement, selectively setting lights on & off, specifying threshold distance to other furniture's for glare computation, etc. are few of the model's user input, enriching its interactive quotient. Besides, building off of just simple line geometry on popular modeling platforms like Revit, it is designed to conveniently get absorbed in the current workflow.

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