# 354: Composing with Light: An inside-out Evaluation of the Role of Intuition and Simulation throughout the Design Process

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**Abstract**

This paper demonstrates a design process, in which intuition and building performance simulation are integrated to guide and inform the decisions in the conceptual and developmental phases. The main sustainable strategy has been identified as daylight harvesting for the refurbishment of an artificially lit pavilion into a library. "*Light as an image of nature"* is a concept that refers to the patches of the sunlight penetrating thru the branches and leaves of trees. This concept is used as the deriving concept in design, where perceptional qualities of space and light are orchestrated with optimal visual performance and visual comfort. Quantitative criteria (illuminance values, daylight factor, daylight autonomy, luminance distributions, and glare analysis) and visual appraisal are used for design evaluation. The resulting design process is iterative, where simulation is used extensively to provide feedback for accelerating and improving the design decisions.

Keywords: daylighting; building performance simulation, perceptional qualities of lighting; daylight autonomy; visual comfort; architectural design process

## 1. Introduction

Building performance simulation has matured significantly in the recent decades. Increased accuracy and fidelity of simulations opened up many opportunities for deployment of better performance analysis tools, techniques, and metrics. However, most of these tools are employed at later design phases: Their usage requires expertise, often acquired through consultancy. Their predictability power depends upon the physically based modeling of geometry, material properties, and other information that can only be determined in later stages of design. Therefore, simulation is used to test whether certain performance criteria are fulfilled after the design strategies are developed and/or most of the decisions are finalized. As a result, its impact on the final design is limited.

Recently, designer friendly simulation tools that provide both visual and numerical feedback have emerged to promote the earlier use of the analytical tools in the design process. However, wide scale adoption and integration into the design process is a challenging issue: The synthesized design solution may be not the most rational alternative, rather the most successful mediation between conflicts, priorities, concepts, and affirmations [1]. Simulation based design approaches raise indirect skepticism as the main intent of any architectural design cannot be reduced to fulfill numerical criteria [2].

This paper demonstrates a design process that incorporates both intuitive and scientific approaches. The underlying ideas are as follows:

(i) Conception of a building design is guided by the goals and constraints of the project, and driven by the intuitive approaches of the design team (ii) Analytical approaches employed throughout the design processes help architects to envision the performance of their designs, accelerate and improve the design decisions, and reduce the uncertainty of the outcome; (iii) Computational approaches enable analysis with detail, flexibility, and rigor that may be infeasible or impossible to achieve with traditional analysis tools and techniques.

## 2. Design Project

The design project used to demonstrate the role of intuition and simulation is a proposal to refurbish the existing *"Fun Forest"* pavilion in Seattle Center (Fig. 1) as a public library. Seattle Center was originally designed for World Expo and today it includes iconic buildings such as the Space Needle (1962) and the Experience Music Project (2001). It is a major gathering place for public events and festivals. The library is proposed to enhance the existing civic character of the Seattle Center.

The aspiration is to design the library as a daylit space: The design criteria include the fulfillment of quantitative lighting requirements for libraries. However, the deriving design concept is to match the perceptional qualities of light patterns penetrating thru the trees, inspired by Pacific North-West landscapes. This inspiration is concurrent with Millet's concept of "*light as the image of nature"* [3]:

*"Counter to revealing the spirit of the place where we are, light can suggest other places and other times. In the face of having lost our constant and natural relationship to the landscape and its light, light can remind us of places that we know through recreating their particular patterns of light, such as shafts of light that penetrate into deep forests".*


*Fig 1. Interior of Fun Forest pavillion.*

Lighting quality and the resultant visual effects can be difficult to prescribe or quantify. Analytical means, like simulation tools, help the designer to demystify the components of the luminous environments to recreate the perceptual qualities and visual expressiveness of light, as experienced in nature or existing designs.

## 3. Design process

The design process is driven by the synergy of considerations as discussed below.

### 3.1 Field studies of lighting patterns

As the first step, perceptional field studies were carried out in forests around Seattle. These studies provide inspiration and understanding of different lighting qualities that is based on properties of materials (translucency, specularity, opaqueness, etc) and light sources (sun light and sky light). They also provide the awareness for a compelling visual environment, which is the result of affluent lighting variations (Fig. 2). Field studies corroborated the initial design concept and formed the intuitive background for the development of the design.

*Fig 2. An example of inspiring lighting patterns in a forest.*

### 3.2 Climate analysis of Seattle

Climate analysis of Seattle (47.6° N, 122.3° W) was carried out by studying the hourly weather data (Typical Meteorological Year). Seattle has a moist mid-latitude climate with mild winters. After analyzing different strategies, exposed mass with night purge ventilation, and natural ventilation were selected as the most feasible passive strategies (Fig. 3), along with daylighting during the library operation hours (10am-8pm).

By applying the selected passive strategies, thermal comfort can be achieved in summer months, eliminating the need for active air-conditioning systems. Wind roses generated for summer months reveal that the dominant winds come from north – south axis. Refurbishment of pavilion included considerations for openings to utilize natural ventilation.

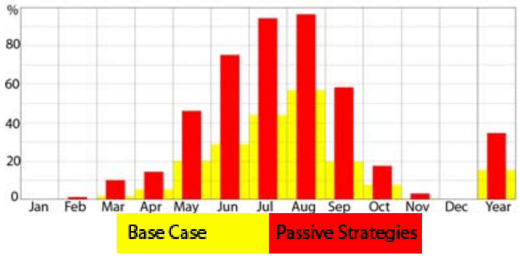


*Fig 3. Efficiency of selected passive strategies (exposed mass with night purge ventilation, and natural ventilation) in Seattle*

### 3.3 Urban design considerations

Fun Forest pavilion is positioned in a unique context. Its eastern façade faces the Space Needle and the Fun Forest Attraction Park. Its northern façade is open to the main pedestrian axis in the Seattle Center. Both Eastern and Northern sides of the building are the major entry points into the building. Existing entrance from the Southern side is preserved while a new entrance was introduced from the Western side. The existing entrances lead to arrangement of the building program in a simple diagram between the two main perpendicular axes (Fig 4). Fig. 5 demonstrates the shadow patterns of the surrounding buildings in the site in one hour increments for the winter solstice.

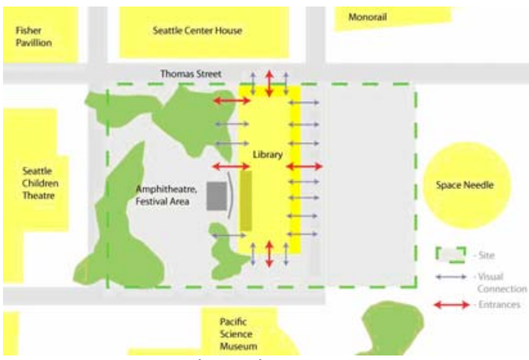


*Fig 4. Site context*

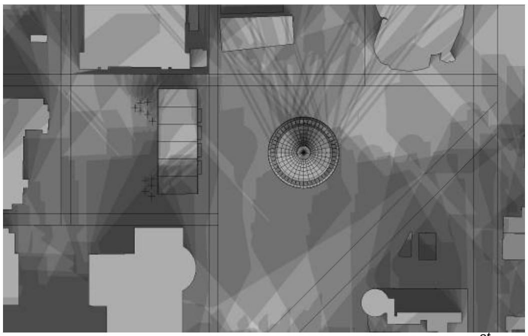

*Fig 5. Butterfly shadow diagram, December 21st.*

### 3.4 Refurbishment strategy.

Site response influenced the reconstruction strategies, where main emphasis is the interaction between the old and the new building. Exterior is designed partly to express the historical layers of the building, while interior is designed to achieve the dynamics of lighting patterns penetrating into the building.

The existing space lacks adequate amount of daylight and it is not a visually stimulating environment. Toplighting is proposed as the principal lighting strategy along with the light diffusing elements that are hung from the ceiling (Fig. 6).

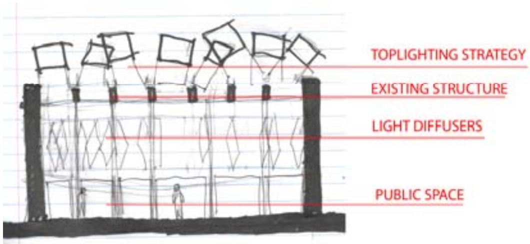


*Fig 6.Sketch of proposed skylights and light diffusing elements hung above the reading areas.*

### 3.5 Evaluation strategies and criteria

The design is developed and evaluated using Radiance Lighting Simulation and Visualization System [4] through Ecotect interface [5]. Radiance is chosen as it is a validated lighting simulation software and Ecotect provides a designer friendly interface for the Radiance software.

The following criteria have been employed throughout the design process:

- Illuminance levels on the task surface: The library should maintain horizontal illuminance of minimum of 300 lux at the work plane (table height of 600 mm) in designated areas for reading activities.

The objective is to achieve the adequate illuminance levels with daylighting throughout the year. To evaluate the criteria, multiple simulations are performed. Initial analysis of design alternatives targeted the worst case scenario for daylight availability: Illuminance levels are studied for December 21st at noon under overcast sky conditions.

Later stages involved studying the daylight levels throughout the year using hourly weather data. This analysis was performed using the daylight autonomy (DA) [6] method, which provides the percentage of the year when the target illuminance (300 lux for the library) is met solely by daylight.

- Luminance levels are kept below 2000 cd/m$^2$ within the field of view to avoid glare problems [7]. The objective is to attain good visibility and maintain visual comfort throughout the space. Luminance maps are utilized to study the absolute luminance values and distributions.

- Luminance variations are sought out within the space to enrich the visual quality of the environment.

- Direct sunlight is precluded from the task surfaces.

### 3.6 Design Synthesis

Throughout the design development, alternative designs are proposed and evaluated. Few of the phases are shown here to demonstrate the iterative process: The first attempt to translate the initial design concept was to lower the ceiling to 5m height in order to create the encircling feeling of a forest (Fig 7).

*Fig 7. Placement of skylights above the reading areas.*

Rough simulations of the corresponding daylighting levels were performed with few alternatives (Fig. 7 and 8). Luminance studies revealed that glazed eastern façade, without any daylight controls, will be significantly brighter than the rest of the space. Based on the simulation results, the usage of translucent glass proved to be sufficient for achieving daylight autonomy, without causing significant glare problems. However, the spatial characteristics of the space were not found very stimulating.

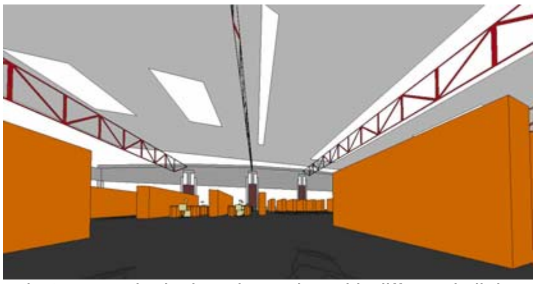

*Fig 8. An early design alternative with diffuse skylights*

The next generation of the design alternatives featured vertical shades on Eastern façade, and randomly folded vertical planes that would act as light diffusers (Fig. 9).

*Fig 9. Initial sketch of folded planes as toplight diffusers.*

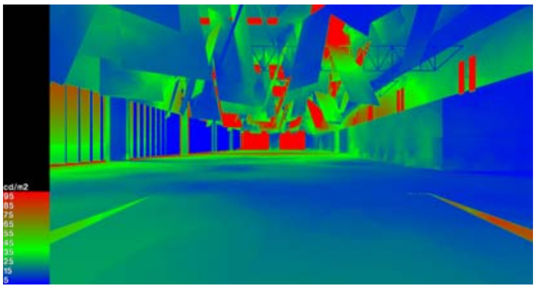


*Fig 10. False color image to study the luminance values and variations.*

These elements control direct glare, while providing light washed vertical surfaces. Analysis results (Fig. 10) illustrate that luminance variations are achieved (pointing to a visually stimulating environment) within a relatively narrow range (pointing to a visually more comfortable environment as compared to the previous design iterations).

From visual and aesthetic points of views, interior with the tectonic elements and the light diffusing layers were considered more promising (Fig. 11). These elements created the envisioned ambience and visual quality. It is conceived as a potentially more contemplative environment that will encourage reading, which is the main function of the proposed design.

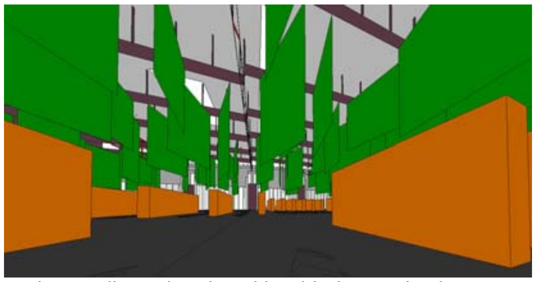

*Fig 11. Library interior with added tectonic elements and light diffusers.*

**3.7 Development of the design idea**

To develop the design further it was necessarily to align the skylights in congestion with the structure and size them to bring in adequate amounts of light even during the overcast winter days. It was also necessarily to develop the light diffusing strategy to minimize the penetration of direct sun. Fig. 12 shows the final sketch of the lighting strategy that consists of square formed light wells and elongated skylights. The design is derived from an intuitive interpretation of few generations of simulations.

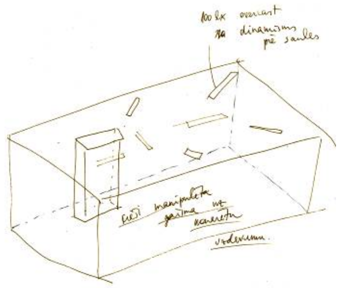

*Fig 12. Principal sketch of skylight concept over the reading areas.*

The principal design idea dictates that the light wells would be large enough to admit enough light (300 lux) in an overcast winter day. The size of the light well openings would create large sun patches on building surfaces unless they are controlled and diffused. The banners around the light wells act as light diffusers. The elongated skylights are added to bring lighting dynamism in the space. Their different orientations is a design decision to allow sunlight only in limited times and locations. The illuminance analysis of the space (Fig. 13) proved that the strategy is working in principle.

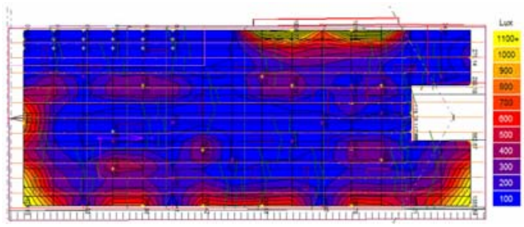


*Fig 13. Illuminance values over the work plane for December 21 at noon under overcast sky conditions*

### 3.8 Design development phase.

For each type of skylight and light well, specific light diffusing layers were developed. Raytracing method is used to trace the sun rays for different times of the day and year. The objective was to block most of the direct sun penetration. Initially they were composed of vertical planes (Fig. 14), but later they were developed into more complex forms.

*Fig 14. Raytracing of light diffusers.*

Renderings (Fig. 15) show the resulting visual richness. The tectonic formation and the associated lighting qualities result in an environmentally sound structure and perceptually inspiring surrounding that encourages and reinforces the activities in the library throughout the year (Fig. 16).

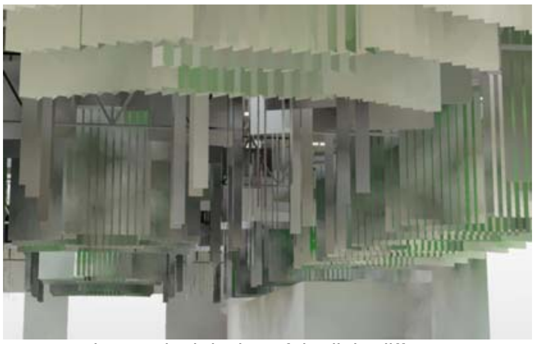

*Fig 15. Final design of the light diffusers*

*Fig 16. Fragment of the section*

At this stage of the design, goals are achieved to a level of satisfaction, so the last step included final (and more refined) lighting simulations and analyses.

### 3.9 Final lighting simulations.

Final lighting analysis was performed to evaluate:
1) Visual effect: How the designed space is perceived under different sky conditions?
2) Visual Performance: What are the illuminance levels under different sky conditions?
3) Visual comfort: What are the luminance variations under different sky conditions (presence or absence of glare)?

*Fig 17. Overcast sky, December 21, 12:00.*

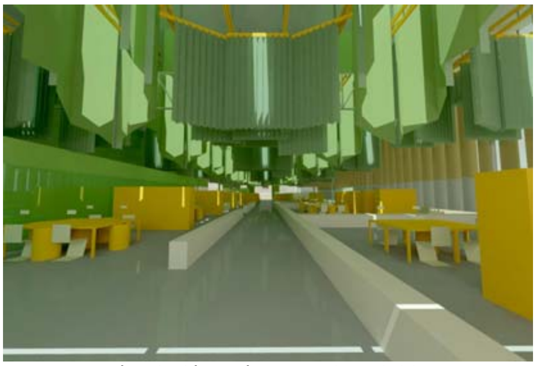

*Fig 18. Clear sky, June 21, 12:00..*

Different lighting patterns achieved on overcast winter and sunny summer days (Fig. 17 and 18), evoke similarities with the qualities of light within a forest and demonstrate the dynamics of the lighting patterns within a space.

Daylight Factor map (Fig. 19) illustrates that daylight factors range from 3 to 12% within the space. Daylight Autonomy is quite even throughout the space. During the daytime operation hours of the library, 300 lx is supplied by daylight alone for the 72% of the year for the majority of the building.

Luminance analyses performed for different positions within the place revealed that:

(i) The skylights enclosed by light diffusing banners provide adequate light without causing glare;
(ii) The Eastern facade is prone to glare (luminance values around 5000 cd/m²) in early mornings. The period coincides with the first working hour of library.
(iii) Even in sunny summer mornings the vertical light diffusers along with the vertical surfaces are within acceptable luminance values (Fig. 20 and 21). However less reflective and specular material properties is proposed in place of the polished concrete on the floor near the eastern facade.

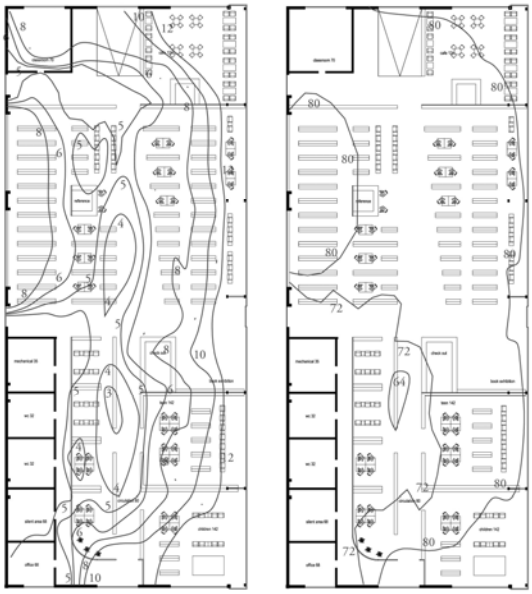

*Fig 19. Daylight Factor and Daylight Autonomy of the space.*

The conclusion of the lighting analyses is that the designed space is successfully daylit: it embodies stimulating perceptional qualities, and it effectively fulfills the numeric lighting design criteria. As discussed above, analysis also revealed few problems that were not foreseen earlier, and they are taken into consideration for further design development. A more detailed version of this study can be found in [8].

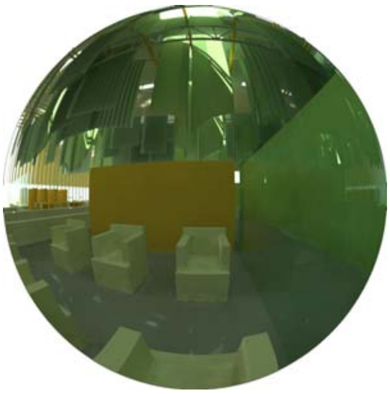

*Fig 20 Fisheye rendering (Clear sky, June 21, 10:00)*

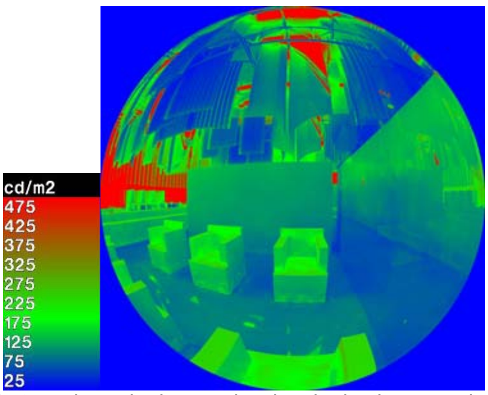


*Fig 21 False color image showing the luminance values and distributions (Clear sky, June 21, 10:00)*

## 5. Conclusion

The iterative usage of simulation is a distinct feature of design process described. It started with a concept. Unlike a process where simulation is used only to verify the design decisions in later stages, the simulation results qualitatively changed the design decisions at early phases; alternative solutions were compared through numerical and visual criteria; and these evaluations led to the re-consideration of the concepts and priorities.

For this approach, it is crucial for the architect to use the right software to at the right time and to possess the relevant skills to interpret the simulation results in their most thought provoking form. Yet, the end result is a fruitful integration where intuitive approaches derive the design ideas and simulation equips the designer with performative measures; consequently opens designer's imagination and capabilities for otherwise risky design decisions.

## 6. Acknowledgements

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