A light of Play: Demystifying Daylight-driven Spatial Sensation Modeling through Image-based Analysis

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Abstract. Our study aims at evaluating the daylight model as a design approach, facilitating the architect to improve spatial quality, and making sense of spatial sensation of a daylight model through a quantitative method of sequential and time-based image analysis. We investigated two spatial criteria affected by light, namely calming and exciting [10], defined by four light indicators: contrast, intensity, uniformity, and colours. The mechanism of the experiment was performed on the process of a conceptual design of a museum of modern art in Bandung, where design decisions of architectural layout and element, space, and form were defined and determined based on the result of analysis over series of rendering images instead of conventional diagram-to-plan approach. In this method, each image contains measures of the predictive perceptual effect of daylight for the decision-making process. On the notes of this study, the quantitative and formal approach through image-based analysis has its benefit to model the intangible aspect of architectural design and potent to improve objective measures of spatial quality.

1. Introduction

Daylight is an essential element of architecture design, especially its significance to deliver natural light that important to both our body and to the environment as well as determine the sensation of a space. The same rooms can have very different spatial impressions by changing the size and location of its openings [7]. Many renowned architects tried to incorporate daylight to their design and use it to highlight their design. For Louis Khan, daylight has its mood that different from artificial light, and according to him, daylight is the only light that makes architecture become architecture [6].

Daylight is never a stationer light source. It is always changing and moving from morning to evening, creating a variety of movements and different effects in every hour. Sometimes it can generate a direct light with a distinct contrast level of brightness between light and shadow, and at the other time, it also can give a diffuse light with smooth and subtle effect. This variation of daylight conditions is an essential element to alter the sensation of an architectural space, creating an illusion in a spatial configuration.

There have been many studies on the quantitative aspect of daylight, but the qualitative aspect of daylight such sensation remains subjective matter [4]. Architects tend to use a trial-and-error approach.
using a scaled model with a direct light source such as a flashlight to simulate a casting shadow or light map being projected into the element of a building. When using a 3D modeling software, this approach still being practice in different media but with the same approach. In principle, elaborating the potential of daylight for creating a sensation in space during the design process is still regarded as an intuitive action that leads to a more qualitative and subjective judgment.

As we know there are two types of daylight method analysis, illuminance-based method and luminance-based method. In terms of measuring the qualitative aspect of daylight, the luminance-based method is more suitable, as it can show the sensation of daylight that experienced by the occupant through rendered images or photographs [5][8]. Several studies have tried to provide a new approach to quantitatively measure the subjectivity of daylight by using digital images [1][4][5][9][10]. HDR photograph image was used in [1] approach to know the user preferences about pleasantness, amount of view, visual comfort, and spaciousness from a space by showing several HDR images of an office space with different luminance level to participant on a special HDR display computer monitor at realistic luminance levels to know the correlation between luminance HDR image with user preferences. [3][4] propose a simpler way by using histogram in a digital-images software by showing the distribution of pixels of the brightness on a raster image. The underlying principle is to calculate the distribution of light properties or indicators using a series of raster images that determine the definition of space affected by light. The histogram will provide information that will help to plot the mean and standard deviation value of digital image which show the brightness and contrast information. Meanwhile [9][10] propose another method to read the contrast, complexity, uniformity, and excitement by using global contrast measurement (Michelson, RMS), and local contrast measurement (Spatial Contrast, RAMMG) on HDR daylight rendering.

From all the example of previous studies, for this case study, the author decided to adapt [3][4] method as it can give simplicity the approach for architects in early conceptual studies to understand the spatial sensation of daylight quantitatively and to take the next step of design decision by using available and familiar technology.

2. Methodology
The methodology consists of two main phases: the collection data and the analysis data. In the data collection phase, we determined what kind of spatial sensations can be generated by daylight. For example, differentiate the spatial criteria into two kinds, namely, calming and exciting [4][10]. Calming space defined by three indicators: indirect or diffuse light, uniformity of light, and low contrast. On the contrary, exciting space defined by three indicators: direct light, non-uniformity of light, and high contrast [4][10].

In the second phase, we explored the design space by conducting a simulation of a case study's sequential images of spatial configuration. At design spaces, we defined an intended design goal such as calming space or exciting space based on its function. Our case study is a conceptual design of a museum of modern art that utilizes daylight to create a spatial sensation. Each space has its spatial sensation, and the determination of spatial sensation will drive the design process.

In general, the museum space divided into three main zones. The first zone is the receiving area consists of the lobby, ticketing, and amenities. The second zone is the temporary exhibition area, and the last one is the permanent exhibition area. The spatial sensation criteria that are calming and exciting will be applied not in all the museum space but only in specific spaces such as in the receiving area, circulation, and a specific exhibition area. When visitors come to the museum, they will first enter the receiving area with a calming sensation. After going through the receiving area, visitors will be directed to the temporary exhibition area. At this stage, visitors will experience an exciting sensation of circulation space that drives visitors to the temporary exhibition area. The last, after going through the temporary exhibition area, visitors then directed to the permanent exhibition area. In contrast to the temporary exhibition area, circulation to and in the permanent exhibition area is conceptualized with a calming spatial sensation.
At the preliminary analysis stage that based on the sequential image renderings, we use VELUX Daylight Visualizer to produce photo-realistic visualization image. We also decided to take a sample of lighting conditions in months that have extreme sun's position: March, June, September, and December. At each month, we determined the simulation time that is 09.00 a.m., 12.00 p.m., and 16.00 p.m. so each space will have twelve rendered images. The series of rendered images of the initial idea of the space then analysed by using histograms data in digital imaging software (we used Adobe Photoshop for this study). The analysed image must be in greyscale mode as it reverses contrast intensity [4].

![Figure 1. Example of using histogram in image-based analysis](image1)
![Figure 2. Example of using histogram in image-based analysis](image2)

Figures 1 and 2 above show the sample analysis using a histogram in an image-editing software. The standard deviation in the histogram may indicate the contrast, and the mean number indicates the brightness. As the standard deviation number increases, it shows higher contrast and uniformity of the light. If the histogram shows a lower number of standard deviation, it means lower contrast and more uniform. According to the classification of lighting ambiance by [4], the range number of standard deviation categorized as low contrast is between 0-75, and the range number of standard deviation categorized as high contrast is between 75-135. This range number becomes the guideline to classify the spatial sensation using image-based analysis. The more the histogram graph is in the dark area (0%) or the bright area (100%), the more even the light distribution will be. The higher number of mean, then the brighter it will be.

On the contrary, the lower the mean number, then the darker it will be. Series of images below are the example figures of using histograms to analyse the space. If the analysis result does not match the initial idea, then design adjustments should be made, and the final design will be developed based on the analysis result.

3. Simulation and Result

![Figure 3. Museum floor plan, elevation, and bird eye view](image3)
The analysis was carried on area B (circulation of receiving area) for calming spatial sensation, and area C (circulation of temporary exhibition) for exciting spatial sensation. The results of the analysis can be seen in the image below.

**Figure 4.** Analysis of circulation at receiving area and sun position on March 09.00 a.m.

**Figure 5.** Analysis of circulation at receiving area and sun position on June 09.00 a.m.

**Figure 6.** Analysis of circulation at receiving area and sun position on September 09.00 a.m.

**Figure 7.** Analysis of circulation at receiving area and sun position on December 09.00 a.m.

**Figure 8.** Analysis of circulation at temporary exhibition and sun position on March 09.00 a.m.
**Figure 9.** Analysis of circulation at temporary exhibition and sun position on June 09.00 a.m.

![Image](image1)

**Figure 10.** Analysis of circulation at temporary exhibition and sun position on September 09.00

![Image](image2)

**Figure 11.** Analysis of circulation at temporary exhibition and sun position on December 09.00

![Image](image3)

**Table 1.** Result of Standard Deviation number for Calming Spatial Sensation

|               | 09.00 | 12.00 | 16.00 |
|---------------|-------|-------|-------|
| March         | 30.58 | 51.83 | 37.11 |
| June          | 28.47 | 45.50 | **22.01** |
| September     | 30.81 | **51.87** | 35.90 |
| December      | 28.69 | 45.42 | 33.85 |

**Table 2.** Result of Standard Deviation number for Exciting Spatial Sensation

|                | 09.00 | 12.00 | 16.00 |
|----------------|-------|-------|-------|
| March          | 53.68 | 49.01 | 34.52 |
| June           | 34.01 | 45.56 | **25.54** |
| September      | 53.30 | 48.24 | 32.10 |
| December       | 47.77 | **53.79** | 44.80 |

4. **Discussion**

The result from each spatial sensation shows different range number of standard deviation as we can see on table 1 and table 2 above. Table 1 shows the result for calming spatial sensation from the lowest standard deviation number 22.01 on June 16.00 p.m. to the highest 51.87 on September 12.00 p.m. As we state before, the range number for low contrast criteria for calming spatial sensation is between 0-75, therefore the result obtained for this space fit into the criteria for calming spatial sensation as we intended. To make this space fit into calming spatial sensation criteria, we deliberately designed a small opening and place it only on the side to gain indirect light, as the only daylight source for this space come from the skylight in the next room.

For the exciting spatial sensation area, we can see the result from table 2, it shows a range number of standard deviations from the lowest 25.54 on June 16.00 p.m. to the highest 53.79 on December 12.00 p.m. As we can see the result doesn’t fit into exciting spatial sensation, instead the result for this intended exciting spatial sensation fall into calming spatial sensation criteria. Therefore, the result
obtained for this space doesn’t match into exciting spatial sensation. This can be caused by the opening design and the position. For this space the daylight falls into the space from the skylight above. At a certain time and month, the light is too weak, and it makes the rendered image become too uniform, whereas we need non uniform result and high contrast image for this criteria. Beside from the opening design, the position of the room that located between two high masses also can affects the light condition.

Further design adjustment needs to be done for both spatial sensations. For the calming area even though it fits the calming spatial sensation criteria, design adjustment still needs to be done because of its function as a circulation. As a circulation it can’t be too dark and need to have a clear orientation even it is still in low contrast range number. For the exciting area, the design adjustment also needs to be done in order to gain a higher standard deviation number. We also need to pay attention to strong incoming light in order to minimize discomfort such as glare.

5. Conclusion
This image-based analysis using histogram on image-editing software is helpful for early design conceptual study, because of its simplicity showing information about brightness and contrast on a rendered image so it can be used as a base for form study. Further research will need to be done by analyzing several design strategies for each spatial sensation criteria, by using more varied opening design, so we have comparison for each spatial sensation. It based on another study that stated that the opening pattern design whether it’s regular pattern or irregular pattern can also affect the subjective and phycological aspect of user [2]. Another thing to note is whether the series type of image-editing software affect the histogram result, as the author use Adobe Photoshop CC 2014.

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