

The Art of Brightness and Darkness: A critical investigation on daylighting quality

WING LAM LO¹, KOEN STEEMERS²

^{1,2}The Martin Centre for Architectural and Urban Studies, Department of Architecture,
University of Cambridge, United Kingdom

ABSTRACT: This paper discusses the precise relationship between daylighting and human perception through controlled screen experiment conducted at the Martin Centre University of Cambridge and field studies at Le Couvent de la Tourette and the Chapel of Notre-Dame-du-Haut, Ronchamp. It aims to examine whether an individual's perception of daylighting should be based not only on luminance and illuminance, but also on the quality of the brightness and contrast. The results demonstrated that a desire daylighting quality can be brought by a sensitive balance of lighting composition. This consists of a dynamic conditions created by windows, various light sources, colours, materials and volume. The relationship between brightness contrast and the multifaceted architectural context is critical to understand daylighting perception in a holistic approach.

Keywords: daylighting quality, perception, brightness, darkness, contrast

INTRODUCTION

The way in which an environment is lit can drastically change an individual's perception of space and, more importantly, life inside that space. In fact, it has been known for quite some time that overexposure and underexposure to daylight can have overwhelming implications for human comfort, health and work performance. Therefore, it is unsurprising that considerable research has gone into daylighting and, in particular, the formation of a methodology by which an individual's response to daylight can be quantified. However, the subject of daylighting can be considered esoteric in nature and is often complicated by the element of human emotion. It would thus be useful to develop a methodology by which an individual's environmental perception can be systematically related to the quality of the surrounding daylighting. This paper explores the precise relationship between daylighting and human perception. It aims to examine whether an individual's perception to daylighting should be based not only on luminance and illuminance, but also on the quality of the brightness and contrast.

This paper presents the insights of daylighting through two stages:

- 1) Controlled screen experiments
- 2) Field studies at Le Couvent de la Tourette and the Chapel of Notre-Dame-du-Haut, Ronchamp.

The field work aims to investigate to what extent the theoretical insights gained from the experiments can be

translated to a multi-faceted architectural context. The controlled studies used the methodology of screen experiments and viewers. Images with various brightness variations were examined against subjective daylighting responses obtained from the participants through questionnaires. The images, with different window configurations and brightness, were analyzed through their luminosity properties, i.e. the pixel distribution of an image. Two new indicators are derived: IM and ISD level. IM denotes as the mean of pixel intensity of an image. This refers to the brightness of a space in which the greater the average pixel value of an image, the brighter the space is. Meanwhile, ISD denotes as the standard deviation of pixel intensity of an image. This refers to the brightness contrast of a space in which the more compressed the range of pixel values of an image, the smaller the contrast of an image is. These concepts are critical in this particular research which attempts to quantify the quality of daylighting as well as searching for a correlation with subjective daylighting perception.

The quality of lighting, which is in need of research attention, was examined using two pairs of perceptions with semantic differential scales: Profane/Sacred and Functional/Poetic. These qualitative aspects of daylighting were seen in the Pilot Study to have a more promising trend with regard to human perception. This therefore prompted additional research in the form of a second set of screen experiments. Finally, the findings were further investigated in two remarkable architectural masterpieces of Le Corbusier. The detailed analysis of the buildings with various light sources, on-site luminous

measurements and IM/ISD studies are presented in the paper which draw invaluable insights on the application of daylighting towards practical luminous environments through the perspective of occupants.

LITERATURE REVIEW

Daylighting research has been well established. It has predominantly focused on daylighting measurement. Knowledge of brightness perception has been heavily emphasized. However, there is little discussion on lighting quality and human perception. The aim of the literature review is to identify the knowledge gap, and to propose a hypothesis: "Daylighting perception should be based not only on luminance and illuminance, but also on the quality of brightness contrast."

Daylighting is a sophisticated subject associate with psychophysics and psychology. Veitch and Newsham expressed them as lighting quality which involves the concern of individual well being, economics and architecture [1]. It has been seen that brightness perception has been researched in depth throughout the history of architecture. Gaps are drawn from the literature review and analyzed in terms of four different areas:

- 1) Visual sensation and perception;
- 2) Daylight factor and other new indicators;
- 3) Biases towards brightness, gloomy, dimness, darkness, shading and shadow
- 4) Contrast and visual performance.

It has been revealed that daylighting research is controversial and it is still under-exploit. Energy efficient (e.g. dimming control), human strong inherent preference for daylighting, visual comfort and task performance are the mostly discussed topics in current daylighting research. Nevertheless, Loe et al. described that "light" and "visual interest" are associated with lighting appearance where "light" and "shade" should be taken into account [2]. However, amongst all these studies, brightness appears to be the main focus. This is not surprising as they aim to admit daylight effectively for work as well as respond to the seasoning requirement. Light has an artistic value which creates poetic spatial quality. In addition to the complexity of the studies, certainly, this scopes for further research, i.e. quality versus quantity.

RESEARCH METHODOLOGY

The research was conducted in a dark boardroom at the Martin Centre, Department of Architecture at the University of Cambridge. This was a controlled screen experiment. Different sets of images with different brightness and darkness were projected onto a screen.

Participants were asked to fill in a specifically designed questionnaire after studying each projected image. All images were generated in Radiance. Each image refers to a space with same or different glazing ratio. It has been undertaken simple image processing technique through the study of luminosity histogram in Photoshop (Fig. 1). Luminosity histogram indicates the distribution of pixel values which evaluates the brightness quality on an image.

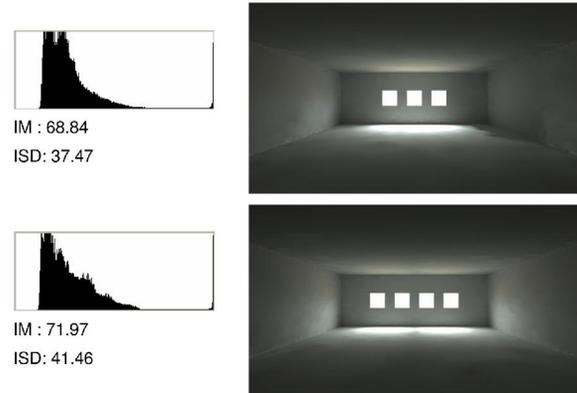


Figure 1: Excerpt from the controlled screen experiment

It is believed that participants who have received architectural training would have bias towards daylighting perception. Therefore, differentiating participants into Architects and Non-Architects could reveal the difference between visually trained and untrained subjects.

SCREEN EXPERIMENT I: PILOT STUDY

The hypothesis has been tested throughout a pilot study against four pairs of semantic adjectives: Profane/Sacred, Relaxing/Stimulating, Dull/Dynamic, Functional/Poetic. These adjectives were designed with reference to the past research conducted by Loe et al [3], and Paripairi, Baker, Steemers and Compagnon [4]. The adjective pairs describe two extremes of an atmosphere. Participants were required rating the space on a given scale (e.g. Profane Sacred).

It is interesting to find that, the less contrasting the space, the more profane and functional the space would be; on contrary, when contrast increases, space becomes more stimulating, dynamic and poetic. Furthermore, slit window has a profound sacred quality of a space. Despite the sample size is relatively small, i.e. 10 architects and 10 non-architects, consistency in some of the trends were found, i.e. Profane/Sacred, Functional/Poetic.

Despite this is a brief pilot study, it indicates preliminary insight on the trend of perception which could be influenced by the degree of brightness variation. Nonetheless, small sample size, unrealistic quality of

presented image, unequal range of IM/ISD, different training background might affect the correlation strength.

SCREEN EXPERIMENT II

The design of Experiment II adopted a similar methodology as that applied in the pilot study: screen experiment. Unlike the images rendered in the pilot study, however, the new set of images covers a wider range of IM and ISD. The exposure of each image was further adjusted in Radiance. There are four tasks in the experiment. Each task has its own set of images.

1. Task One aims to explore the following six parameters: Brightness-Dependent (IM), Contrast-Dependent (ISD), Window Geometry, Window Shape, Window Area and Number of Window.

The size of the rendered rooms is constant, i.e. 9m(h)x15m(w)x15m(d). Each of the single opening area is the same, i.e. 4m². The dimension of each single opening in Scenario A, B and C are 2m(h)x2m(w), 4m(h)x1m(w) and 8m(h)x0.5m(w), respectively (Fig. 2). The purpose of keeping the opening area constant is to minimize the number of variables in the experiment.

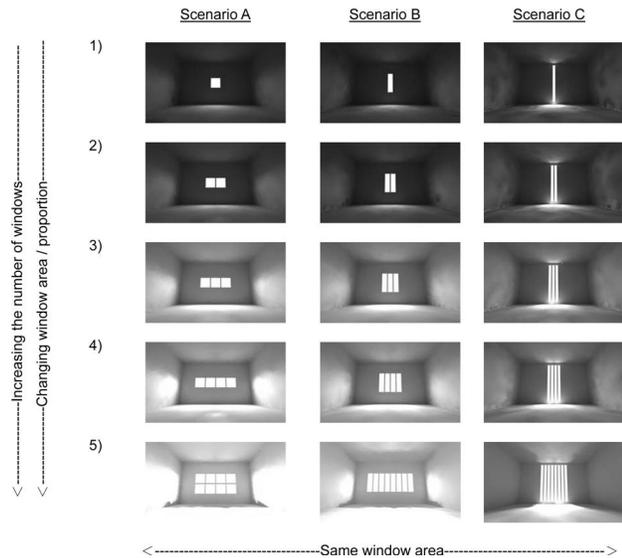


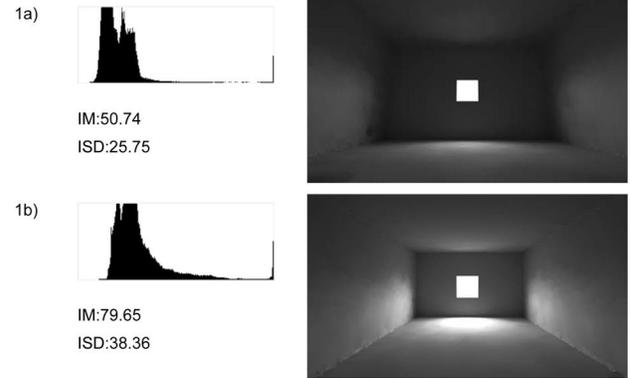
Figure 2: Screen experiment II – Task One

2. Task Two aims to explore the relative room size as a testing parameter. This is a section of comparative judgment. This intends to form inter and intra group comparison. There are three groups: Group 1, Group 2 and Group 3. The room depth of these groups remains constant, i.e. 15m. However, the window areas of the main façade can vary (Fig. 3).

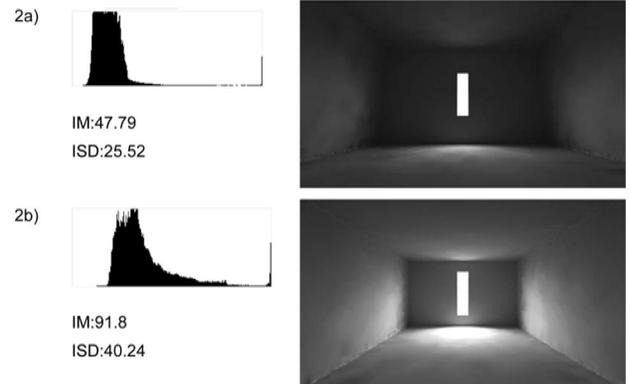
3. Task Three aims to explore the presence of shadows (sun patch) as a testing parameter.

4. Task Four aims to argue from theoretical assessment to real building assessment. Three buildings in Cambridge were chosen: 1) Darwin College Study Centre; 2) Kettle’s Yard Museum and 3) Fitzwilliam College’s Chapel. This is an open-ended question. Respondents were required to answer two questions on function and lighting quality of the space: 1) What kind of activity might this space be used for? 2) Describe the lighting quality of this space.

Group 1 – a:b = 3:2



Group 2 – a:b = 3:2



Group 3 – a:b = 4:3

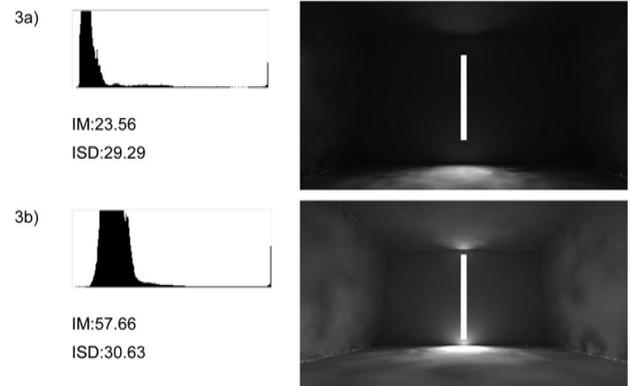


Figure 3: Screen experiment II – Task Two: various room sizes as testing parameter.

CASE STUDIES

The Screen Experiment is a controlled laboratory setting. In this section, the investigation would be furthered in two remarkable buildings of Le Corbusier in France: 1) Le Couvent de la Tourette in L'Arbresle and, 2) Notre-Dame-du-Haut in Ronchamp. The case studies aim to obtain insight on how the brightness variation influences human perception in reality. This proposes to understand daylighting perception in a holistic approach. The structure of the case study analysis is subdivided into two parts:

Case Study 1: Le Couvent de la Tourette This section explores and captures the transition of daylighting perception from one luminous environment to another. This aims to reveal how various luminous quality, types of lighting (i.e. diffused light, direct light and reflected light), window configurations and other factors could influence human daylighting perception. Five spaces were examined: Guest Room, Cell, Corridors and Atrium, Church and Crypt.

Case Study 2: Chapel of Notre-Dame-du-Haut (Ronchamp Chapel) This section confines the insight of daylighting perception to a specific architectural typology – Sacred Space. A comparative analysis between the Church at La Tourette and Ronchamp Chapel would be conducted. This aims to validate the trend of daylighting perception and brightness variation in a specific context.

Respondents, visitors and architectural students, were asked to evaluate the acceptability and appropriateness of the luminous environment as an overall evaluation. A survey was conducted on site with a sample size of twenty participants for each case study. They were required to rate the brightness level with the given scale of “Small contrast Great Contrast”. Similar to the screen experiment, respondents were also asked to rate the perceptual quality on two semantic scales:

- | | |
|---------------|--------|
| 1) Profane | Sacred |
| 2) Functional | Poetic |

This was designed to allow further research of the insight achieved from the theoretical studies into a real context of architecture. It is worthwhile to emphasize that, unlike Screen Experiment II, where respondents perceived through images, respondents from La Tourette and Ronchamp Chapel perceived in an actual luminous environment. The perceptual responses would be correlated with IM, ISD, illuminance, luminance and daylight factor. This measuring of physical quantities had been done on-site using luminance and illuminance meters. This aims to place the earlier research and insight into a real multifaceted context. Nevertheless, this allows

further investigation into the relationship between physical quantities, i.e. luminance and illuminance, and the visual sensation in the reality.

The analysis between IM/ISD and human perception aims to place the earlier theoretical research into the reality. The result of IM indicates that human has a similar perceptual pattern in both generic and real context. The correlation analysis between IM and Profane/Sacred and Functional/Poetic gives a negative Pearson Correlation Value of $-.364$ (sig. $=.02$) and $-.137$ (sig. $=.148$) respectively. The negative value implies that the space would be perceived as being more profane and functional when it gets brighter similar to that obtained in Experiment II. Compare to Experiment II, La Tourette has a moderate IM (between 90 to 150), which follows the trend of Category II in IM perceptual graph obtained in Experiment II.

On the other hand, it is surprising to find out the relationship between ISD and human perception has a statistically significant result. The Pearson Correlation of Profane/Sacred and Functional/Poetic is $.422$ (sig. $=.000$) and $.425$ (sig. $=.000$) correspondingly. The Pearson Correlation values are positive which indicate the space perceived to be more poetic as contrast increased. These reassure the trend obtained from Experiment II. Compare to Experiment II, La Tourette has a relatively high ISD (above 55) which does follow the trend of the Category III in ISD perceptual graph obtained in Experiment II. This implies the correlation is approximately the same. The more diverse the lighting pattern, the more sacred the space would be.

It is interesting to discover that there are statistically significant results for the relationship between luminance/illuminance/daylight factor and the perception of Profane/Sacred. They all have negative Pearson Correlation values. However, the correlation between luminance/illuminance/Daylight factor and Functional/Poetic is relatively weak. Indeed, two of the regression studies have null results: 1) The relationship between luminance contrast (standard deviation) and Functional/Poetic and 2) The relationship between average illuminance and Functional/Poetic. Apparently, this presents significant challenges when placing theoretical findings in to the real complex context. In generic setting, the investigation has isolated on specific parameters: brightness, contrast, room size and window configurations. Therefore, it is not surprising to have null results in the real context, where ISD/IM does not correlate with the perceptual responses. This is because orientation, volume, texture, materials and colours could further increase the complexity of the overall lighting composition.

“The light seems to be speaking in the silence,” one of the visitors commented. The quantitative and

qualitative results of Ronchamp Chapel reassure the insights achieved from the theoretical study and the real world (Case Study 1: La Tourette). Compared to the IM/ISD of Experiment II, Ronchamp Chapel and the Church of La Tourette both have a fairly low brightness (IM) but high contrast level (ISD) which does follow the perceptual trends obtained from Experiment II. These two spaces are perceived similarly as being sacred and poetic.

Ronchamp Chapel and the Church of La Tourette adopt the same core aspects of light (i.e. direct, diffused and reflected light), design concept of slot windows and the variation of window sizes, geometry and colors. These diversities enrich the overall light pattern, the liveliness and the poetic quality of the space. Ultimately, these justify and confirm the sacred perception in a dimly lit luminous environment.

CONCLUSION

Results from the controlled and field experiments confirm that an individual's perception of an environment can differ substantially depending on his or her visual training. For example, Architects and Non-Architects were shown to perceive differently in many instances. This research also finds that, in addition to being affected by luminance and illuminance, an individual's perception of a space also depends on the contrast between brightness and darkness. It is therefore important to seek an optimal balance in lighting composition in order to impart a sense of quality into a space. This must be achieved through a holistic approach involving careful manipulation of texture, colour, material, and context. This informs how we perceive a multifaceted space through the natural power of light with overlapping of sensations.

Four important insights were gained:

- 1) Architects have more consistent perceptions of daylight and more collective responses than Non-Architects. This implies that architectural training does indeed have an effect on how occupants perceive.
- 2) When IM increases (i.e. brightness increases), spaces are perceived as being more profane and more functional.
- 3) When ISD increases (i.e. contrast increases), spaces are perceived as being more sacred and more poetic.
- 4) It was found that a stronger correlation and a more consistent trend on daylighting perception could be found with respect to the number and shape of windows than merely with brightness and contrast. Increasing the number of windows shifts the perception from being more sacred and poetic to more profane and functional. When the shape of a window gets narrower (e.g. slit windows), there is a tendency to be perceived as being more sacred.

These insights were examined in the context of real architecture, i.e. field studies, which is a more holistic approach when compared to the controlled experiments. The analysis of subjective responses did confirm the key theoretical findings. The case studies demonstrated that dynamic conditions created by windows, rooflights, various light sources (i.e. direct, diffused and reflected light), colours, materials and volume, in relation to the brightness and darkness, mean that a space can be revealed vibrantly. Brightness and contrast have been seen as critical in understanding daylighting perception. However, the desired quality of light can be brought about by a sensitive balance of lighting composition. Discarding complex daylighting measurement and indicator, a simpler approach has been adopted in the research, i.e. simple profiling through the application of Photoshop. This is a relatively simple approach for gaining insight into an undoubtedly complex subject. In future work, an improved version of this approach (i.e. the use of High Dynamic Range images) should be adopted in order to achieve a more objective analysis of the luminance distribution.

It is worth noting that the insights gained from the theoretical study might perhaps be seen as narrow and conditional. However, these theoretical insights indicate statistically significant results and even null results in the cases of the real context. Isolating specific parameters for testing against human perception presents significant challenges in the context of real and complex architectural environments. Therefore, the controlled experiment, including the studies carried out by Newsham et al [5], could be seen as a small step in understand how we perceive architecture in reality. Nonetheless, this paper ultimately reveals how poetic quality of lighting can be shaped. This requires the appropriate adoption of lighting strategies from the occupants' perspective.

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