Celebrating Contrast and Daylight Variability in Contemporary Architectural Design: A Typological Approach

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ABSTRACT

The perceptual performance of architecture can be greatly altered by the ephemeral quality of daylight. Unlike artificial light sources, which can be adjusted to meet performance criteria regardless of geographic location and time of day, daylight is a variable source of illumination. When used to illuminate the static environment of a building, sunlight can dramatically alter our perception of interior architecture. Despite a wide range of daylight design strategies, neither high nor low levels of contrast and variability are synonymous with performance: it is the specific conditions that must be engaged appropriately within the context of each architectural work. While there have been several attempts at quantifying brightness and luminance diversity in daylit architecture (through the use of digital images), we have yet to see a method that can measure the spatial *and* temporal diversity of light within the visual field. In order to establish the importance of luminous composition within interior architecture, this paper presents a survey of contemporary architecture from around the world to develop a more effective vocabulary about contrast and temporal variability under daylight conditions. This survey allows us to grasp the broad range of design strategies employed within contemporary architecture and develop a matrix of contrast typologies against which each space could be compared on a relative scale from high to low. This matrix allows us to develop a precise language about the composition of perceptual luminosity within each space and helps architects to contextualize and compare the perceptual impacts of daylight within space.

Keywords: e.g. Daylighting Design, Contrast, Variability, Architectural Typologies

1. INTRODUCTION

Daylight is an important asset to architectural design. It provides natural illumination for interior space and can greatly enhance architectural form. A growing desire for energy independence, driven by the environmental conscience of the late 20th century and a preoccupation with offset electricity consumption, has led to the widespread development of task-driven illumination metrics (Reinhart & Mardaljevic, 2006). Visual comfort metrics, particularly those pertaining to glare, have also gained predominance within the last decade, due to advances in computational power, which have helped to facilitate time-intensive simulations (Jakubiec & Reinhart, 2012). Perceptual performance indicators, on the other hand, have been traditionally thought of as qualitative design factors and research into the spatial and temporal diversity of the visual field has been limited. Although subjective in nature, the perceptual performance of space is central to architectural design and will often rank above other more tangible or clearly defined evaluation criteria within the design process. With this in mind, it is important to consider perceptual performance criteria alongside illumination and comfort metrics to develop a more holistic understanding of daylight performance in architecture. A brief review of existing daylight performance metrics will help situate this paper and underline the importance of the proposed approach.

The most ubiquitous metrics used today can be divided into two main categories; illumination for task-performance and visual comfort for task-performance. A third, less established category, but one of particular relevance to this paper, is composed of studies that relate occupant preference to perceptual factors (i.e. brightness and luminous diversity) within the occupant's field-of-view.

1.1. Task-Driven Performance Metrics

Over the past several decades, there have been significant improvements in our understanding of daylight as a dynamic and variable source of illumination. We have transitioned from static metrics such as like Daylight Factor DF (Moon & Spencer, 1942) to annual climate-based metrics such as Daylight Autonomy DA (Reinhart & Mardaljevic, 2006) and goal-based metrics such as Acceptable Illuminance Extent AIE

(Kleindienst & Andersen, 2012) to account for a more statistically accurate method of quantifying internal illumiance levels (Mardaljevic, 2000). Visual comfort metrics, such as Daylight Glare Probability DGP (Wienold & Christoffersen, 2006), considered the most reliable index for side-lit office spaces under daylitght conditions, have also evolved into dynamic annual metrics such as DGPs (Wienold, 2009) which provides a comprehensive yearly analysis of glare, with limited computational intensity (Jakubiec & Reinhart, 2012).

While task-driven illumination metrics such as DF and DA can be used to determine whether an interior space is sufficiently illuminated for the performance of visual tasks, comfort-based luminance metrics such as DGP and DGPs allow us to evaluate the visual field for sources of glare-based discomfort. Lighting research has been historically dominated by task-performance and visual comfort criteria, but these metrics are only applicable in spaces where visual tasks are frequently encountered. For spaces where visual task performance is less indicative of lighting performance, we have historically relied on subjective criteria – at which point we seek to create acceptably bright or visually engaging environments (Cuttle, 2010).

1.2. Perceptual Daylight Metrics

Two dimensions that are widely accepted to impact the field-of-view are average luminance and luminance variation (Veitch & Newsham, 2000). The former has been directly associated with perceived lightness and the latter with visual interest (Loe et al., 1994). To evaluate the visual impacts of luminosity within interior architecture, existing research has relied on mean luminance or *brightness*, threshold luminance, and luminance variation in line with occupant surveys to establish trends in preference. Survey-based studies most commonly rely on high-dynamic-range HDR images, digital photographs or renderings produced through Radiance, which provide an expanded range of photometric information, allowing us to evaluate characteristics such as brightness and contrast (Ward, 1994; Newsham et al., 2002). While some studies found that both mean luminance and luminance diversity within an office environment contributed to occupant preference (Cetegen et al., 2008), others have discovered that luminance distribution across an occupant's field-of-view (Tiller & Veitch, 1995) as well as the strength of variation were factors in preference (Wymelenberg & Inanici, 2009).

The problem with those studies that rely on average luminance, luminance range, and standard deviation, is that they cannot asses the *spatial* or *compositional* diversity of luminance values within an occupants' field-of-view. The LD index, which proposes a new method for measuring luminance diversity, relies on eye-level luminance measurements and calculates the difference in luminance levels across a range of acceptable angles correspodning to eye and head movement (Parpairi et al., 2002). A study, which calculates the LD index across three selected view positions, found that luminance variability was highly appreciated by the participants and that variability rather than power were found to contribute to occupant satisfaction. While the LD index proposes a method for analyzing the *spatial* diversity of luminance values across an occupant's point-of-view, it does not address the *temporal* impacts of these visual effects. Furthermore, the method relies on physical measurements in live space, which can pose a number of practical problems and sources of error, such as the movement of people, access requirements, and the disruption of equipment.

In summary, existing research has produced conflicting results regarding the magnitude of preferred contrats and luminance variability in architecture: while some studies have found a relationship between increased luminance diversity and positive preference (Cetegen et al., 2008) (Parpairi et al., 2002), others have found that while some variation in luminance creates a stimulating environment, excessive variabiability tends to create uncomfortable spaces (Wymelenberg & Inanici, 2009).

Through a survey of architecture from around the world, we propose a typological strategy for categorizing space in terms of contrast and temporal variability. This typological approach serves two purposes: on the one hand, it helps us to understand the broad range of daylight strategies within architectural design and on the other hand, it allows us to develop a precise language about the strength and composition of perceptual luminosity within each space. The objective is to generate a quantitative method for analyzing *spatial* and *temporal* diversity through the medium of digital images. The metrics that are being developed as a result of this typological study have been introduced (Rockcastle & Andersen, 2012; Rockcastle & Andersen, in press), and are expected to ultimately help architects to measure and compare the dynamic perceptual impacts of daylight within space.

2. DEVELOPING A TYPOLOGICAL FRAMEWORK

To introduce the range of daylight strategies deployed within contemporary architecture, we will look at three examples and discuss the differences inherent in their expression of spatial and temporal variability. The first example is Norman Foster's renovation of the Kogod courtyard of the Smithsonian American Art Museum Washington, D.C (Figure 1). Completed in 2007, the articulated glass roof, which was inserted into the existing building, emits direct sunlight through a 'fishnet' pattern of light and shadow across the walls and floor of the interior (Ouroussoff, 2007). Designed for temporary occupation and public gathering, the space does not require a tightly controlled lighting strategy. On the contrary, the Kogod Courtyard uses transparency to create a diverse and visually engaging environment, embracing direct sunlight and dynamic visual effects.

The second example is the Church of St. Ignatius in Seattle, Washington, designed by Steven Holl (Figure 2). Unlike the Kogod Courtyard, this space transforms sunlight through a series of soft and indirect luminous forms (Holl, 1999). This architectural space creates a 'carefully calibrated glow' (Ryan, 1995) and produces a dramatically different use of sunlight than the Kogod Courtyard. The interior maintains a dynamic relationship with exterior light levels as shifting sun angles and weather patterns create smooth, yet dramatic transformations to the chapel.

Figure 1 – Kogod Courtyard
Architect: Norman Foster

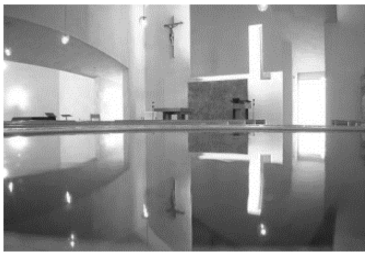


Figure 2 – Chapel of St. Ignatius
Architect: Steven Holl

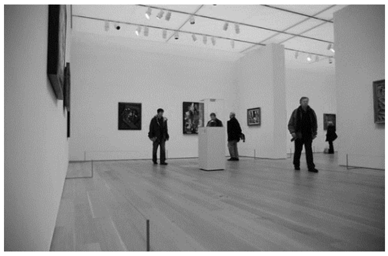


Figure 3 – Chicago Art Institute, The Modern Wing *Architect: Renzo Piano*

The third example is the Modern Wing at the Chicago Art Institute, designed by Renzo Piano Building Workshop and completed in 1997 (Figure 3). Art galleries require controlled lighting environments to protect artwork from UV damage and minimize veiling glare. The roof of the modern wing is composed of two layers: the first layer is made up of white, curved louvers that block direct sunlight, while the second layer contains translucent glass to further diffuse incoming light. As a result, the galleries receive diffuse and uniform daylight which is dynamic in overall brightness, but relatively static in contrast levels due to the lack of direct sunlight.

These three examples illustrate the role of luminous composition in the visual performance of daylit architecture. While each of the strategies varies in its integration of spatial and temporal diversity, all three could be considered successful in achieving an intended set of visual effects which strengthen the spatial experience. Furthermore, the composition of luminance levels, rather than mean luminance or luminance range appears to play a critical role in our perception of contrast. Using these three examples as a starting point, we conducted a global survey of contemporary architecture to catalogue the range of light-based visual effects and rank the resulting typologies in terms of spatial and temporal variability.

3. THE ARCHITECTURAL CONTRAST MATRIX

To develop the matrix, each architectural example was studied using the authors' trained intuition and then positioned within a linear gradient to represent the degree of perceived spatial and temporal variability within each photograph. The process involved each authors' assessment of spatial contrast and variability within each image and a discussion on its relative position within the gradient. When individual images appeared to contain similar contrast characteristics, they were added to an existing category, but when images showed unique characteristics, they formed a new category. Although a total of 75 architectural spaces were initially placed into 15 categories (Rockcastle & Andersen, in press), the authors narrowed the final matrix down to 10 categories, each of which contain 5 exemplary spaces (Figure 4).

The horizontal axis of the matrix shows a linear gradient from high spatial and temporal variability on the left to low spatial and temporal variability on the right. The 50 examples were taken from across the world and represent a diverse mix of architectural designers. Each photograph was selected for its representative perspective of the interior space while most photographs show choreographed views chosen by the architects for publication purposes.

Figure 4 – Matrix Showing Spatial and Temporal Variability for 60 Architectural Spaces (High Spatial Contrast & Temporal Varibaility on the Left to Low Spatial Contrast & Variability on the Right)

Those typologies that fall on the left end of the spectrum are labeled as *Direct and Exaggerated*, *Direct and Dramatic*, and *Direct and Screened*. The *Direct and Exaggerated* category includes highly variable top-lit spaces such as the Kogod Courtyard by Norman Foster and the Milwaukee Art Museum by Santiago Calatrava. The *Direct and Dramatic* category includes side-lit spaces that emit large light patches, such as the Mikimoto Store by Toyo Ito and the Zollverein School by SANAA. The *Direct and Screened* category contains examples of facades or roofs that emit small, but frequent patches of direct sunlight, like the Benavidas Warehouse by Guillermo Hevia and the Dominus Winery by Herzog and deMeuron.

Those typologies that fall toward the middle of the spectrum are labeled as *Partially Direct*, *Direct*, *Selectively Direct*, and *Direct/Indirect*. The *Partially Direct* category contains side-lit spaces that emit sunlight through louvers or repetitive façade elements. Spaces in this category include the Magney House and the Fletcher Page House by Glenn Murcutt. The *Direct* category includes side-lit spaces with minimal obstructions (i.e. no louvers) such as the Bomballa Farmhouse by Collins & Turner or the Farnsworth House by Mies van der Rohe. *Selectively Direct* contains spaces that emit sunlight in discreet instances, such as the Tulach a Tsolais monument by Scotta Tallon Walker or the Imperial War Museum by Daniel Libeskind. The *Direct/Indirect* category is composed of spaces that emit sunlight through thickened openings in the building envelope, resulting in both direct sun patches and an indirect wall wash. Spaces in this category include the Poli House by Pezo Von Ellrichshausen and Notre Dame de Haut by Le Corbusier.

The categories that fall toward the right end of the spectrum are labeled *Spatial Indirect*, *Indirect*, and *Indirect & Diffuse*. The *Spatial Indirect* category is defined by spaces that emit indirect light across interior surfaces. This category includes spaces such as the Chapel of St. Ignatius by Steven Holl and the First Unitarian Church by Louis Kahn. The *Indirect* category contains spaces that emit indirect light through north facing monitors or openings in the roof. Spaces in this category include the Dia Beacon Museum by Open Office and the High Museum of Art by Renzo Piano. And finally, the *Indirect and Diffuse* category contains spaces that utilize diffusing surfaces to minimize the dynamic effects of light and shadow. The Chicago Art

Institute by Renzo Piano and the Louis Vuitton Building by Jun Aoki are examples from this category. These ten categories, although not exhaustive, illustrate a broad range of daylight strategies in contemporary architecture.

4. THE TYPOLOGICAL MATRIX

Using this matrix as reference, we then created a simplified spatial model for each of the ten categories in Figure 4. These simplified spatial models allow us to generate annual renderings and compare the impacts of spatial and temporal diversity across the year, while referring back to the typological matrix. Each of the models in Figure 5 were digitally modelled in Rhinoceros (http://www.rhino3d.com, 2007) with consistent parameters for the floor area, ceiling height, and camera location. The cameras were positioned to face South and centered in the East-West direction to capture an even distribution of wall, floor, and ceiling surfaces within each view. The DIVA for Rhinoceros toolbar (http://www.diva-for-rhino.com, 2009) was then used to export the camera view to Radiance using default reflectance values for floor, wall, and ceiling surfaces. These images, which capture a single snapshot of time, are meant to illustrate a similar gradient of effects as the full architectural matrix in Figure 4. While photographs of existing architectural spaces provide us with more complex information about the effects of sunlight throughout our visual field, HDR renderings of abstract spatial models allow us to more objectively compare the resulting perceptual effects over time. Using these digital models, the authors were able to render annual image sets and apply the quantitative metrics (Rockcastle & Andersen, 2012) developed as a result of this intuitive study. An example of these image sets is shown in Figure 6, which reveals the degree of variability that occurs throughout a selected view of a two abstract top-lit spaces. The date and time of these 56 renderings was established using a time-segmentation method developed for Lightsolve, a goal-based daylight simulation platform originally developed at MIT and now at EPFL (Andersen et al., 2013; Andersen et al., in press), which generates 7 daily and 8 monthly intervals (Kleindienst et al., 2008).

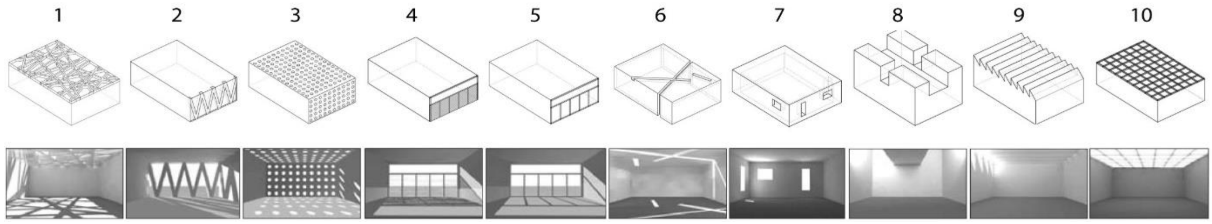
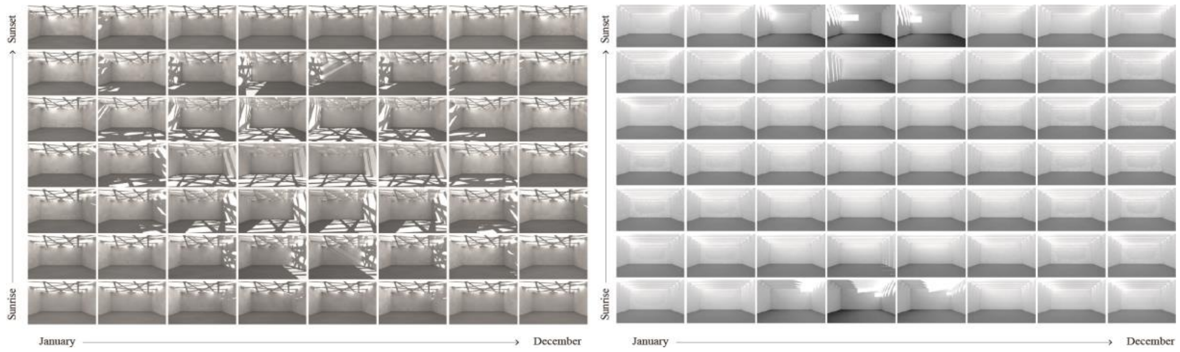


Figure 5 – Matrix Showing 10 Typological Models (High Spatial Contrast & Temporal Variability on the Left to Low Spatial Contrast & Variability on the Right)

The *Direct & Exaggerated* top lit space in Figure 6a shows a highly contrasted interior with variable strength and composition due to the temporal dynamics of sunlight. The *Indirect* top-lit space in Figure 6b, however, shows a relatively static interior with low contrast - except for sunrise and sunset in the summer months when sun penetrates the North-facing roof monitors. These annual sets of images show the degree of luminous variability that occurs throughout each selected view and illustrates the need for metrics that can assess the spatial *and temporal* diversity of light from an occupants' perspective. While spatial diversity can be analyzed within a static image, temporal diversity (resulting from daylight) requires a multitude of images, taken throughout the year, to help designers evaluate the strength and diversity of contrast-based perceptual effects over time.

5. CONCLUSION

From the matrix in Figure 4, we have presented a broad range of architectural examples to show how daylight impacts our perception of interior space through the composition of luminous effects. While existing daylight metrics can account for the dynamics of task-plane illumination and discomfort-glare, methods of assessing human preference toward the field-of-view do not currently account for the *spatial and temporal diversity* of lighting effects from an occupants' perspective. The authors' are currently developing a new set of quantitative metrics that address these characteristics using digital images of interior architecture. While the initial metrics have been pre-validated against the intuitive gradient of abstract images studies shown in Figure 5 (Rockcastle & Andersen, 2012), future work will include a more robust validation of these metrics through detailed architectural examples and occupant surveys.



a) Direct & Exaggerated Top-Lit Space in Boston b) Indirect Top-Lit Space in Boston

Figure 6 – Annual Renderings for a Two Top-lit Spaces in Boston 56 Radiance renderings with even daily hourly and daily subdivisions to represent a full year (Kleindienst et al., 2008) - Latitude 42°N, sunny skies

This work seeks to expand our understanding of contrast-driven visual effects and their dynamic impact on daylit arhcitecture. In order to quantifying these perceptual effects, the authors' have used the architectural and typological matrices presented in this paper to understand the impacts of luminous composition. It is not the average brightness or range of luminance values present within each image that create an impression of contrast, but rather the composition of light and shadow, its strength, and variability over time.

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