

Visualizing Perceptual Dynamics in Architecture

By Siobhan Rockcastle and Marilyne Andersen

“A building speaks through the silence of perception orchestrated by light.” [1]

Most designers would agree that natural light is essential to the experience of any great work of architecture, but as a professional discipline, we lack consensus on *which* characteristics of daylight quantify or qualify the visual performance of a space. Perceptual qualities such as brightness, contrast, and temporal variability influence our experience of physical space and while illumination, both natural and artificial, adds depth to complex geometries, daylight infuses otherwise static interior spaces with shifting compositions of light and shadow. Unlike artificial light sources, which can be adjusted to meet a desired visual effect regardless of location and time, daylight is sensitive to an array of influences. The latitude of a given location affects the length and intensity of daylight hours throughout the year, while local changes in climate affect its hourly strength and variability. Surrounding site conditions can amplify or diminish the sun’s ability to penetrate an interior space and it’s often difficult to predict how these conditions will change over time. Architecture is greatly altered and enriched by the dynamic visual qualities of daylight, yet it is most often valued simply for its ability to provide *adequate* illumination and evaluated through surface-based measurements which do not account for the rich diversity of composition within the field-of-view. While there is some agreement on the minimum amount of illumination that is required for the human eye to perform visual tasks, there is a lack of consensus on how much contrast or brightness makes a given space *visually appealing*.

Architects are trained to place value in the concept of spatial experience and yet heightened environmental awareness has forced designers to meet both functional, aesthetic, and simultaneously ‘high-performance’ quantitative targets. We hear a lot about the importance of net energy balance, thermal and visual comfort, and carbon neutral design, but as these requirements become more pervasive in professional practice and the justification of design quality, we may ask ourselves: how do we prioritize these technical criteria and how should they drive the design process? Somewhere along the line, perceptual qualities of illumination became secondary in our dialogue about daylight performance and this schism between criteria: illumination-based (i.e. do we have enough light to perform a visual task?), comfort (i.e. do we feel a lack of discomfort in these luminous conditions?), and aesthetic (i.e. do we like the composition of these luminous conditions?), causes a dilemma for lighting designers. Architectural lighting must ‘perform’ to meet both illumination, comfort, and aesthetic criteria and we must work to re-establish the role of perceptual indicators in our language about environmental performance [2].

Despite decades of research, we may ask ourselves: why is it so difficult to establish global performance criteria for daylight design? Through research, we know that humans can reach consensus on thermal and acoustical thresholds for comfort, but lighting performance – which is visually perceived – is intricately linked to the form and spatial sequence of a building. As a result, existing guidelines for lighting focus on criteria which can be objectively defined, such as illumination thresholds and discomfort glare. While architects know that too little light is undesirable, they also know that when a design meets illumination thresholds it does not automatically achieve good lighting quality. The visual appearance of light is undeniably important and yet we lack tools to objectively evaluate daylight composition from a human point-of-view. Two spaces which are dramatically different in lighting ambience can produce equally high 'quality' lighting environments depending on programmatic use and design intent. The difference in lighting composition between two spaces, while difficult to evaluate in binary subjective terms (i.e. good or bad), *can* be assessed for objective daylight-induced visual effects (i.e. dramatic or diffuse) and the variability of these effects over time (i.e. dynamic or static).

Through a comparison of three architectural spaces, we will present a range of daylight design strategies which vary in their approach to daylight distribution, yet reinforce a specific spatial experience. In Norman Foster’s renovation of the Kogod Courtyard in Washington, D.C (figure 1), the articulated glass roof above the courtyard creates a dynamic top-lit space with direct sunlight penetration casting a contrasted grid-like pattern of light and shadow onto the walls and floor of the interior space. Designed for temporary occupation and public gathering, the courtyard does not require a tightly controlled lighting strategy. On the contrary, Foster uses transparency to create a dynamic and visually diverse environment.

In Steven Holl's Church of St. Ignatius in Seattle, Washington (figure 2), sunlight is composed into a series of carved, indirect figures which highlight the intersection between different geometries [3]. The light within this church could be described as selectively diffuse, with small window openings that create an indirect wall-wash and fill recessed geometries with a smooth gradient of light. The composition of light within this example changes less abruptly than that of the Kogod Courtyard, but still maintains a dynamic relationship to the exterior as shifting sun angles cause figural volumes of light to change over time [3].

In the Dia Beacon Museum in upstate New York (figure 3), Robert Irwin and Open Office employed a fully-indirect daylighting strategy as north-facing monitors on the roof collect and distribute diffuse light from the north. As a gallery, the space necessitates an even distribution of internal lighting levels, while preventing any direct sunlight that may cause damage to or distract from the artwork. As a result, the presence of strong compositional contrast and temporal instability is minimized throughout the space.

These three examples represent varied site conditions, both urban and rural; varied latitudes, from Washington D.C. to Seattle; and a range of programmatic uses from art gallery to public atrium. They represent dramatically different compositions of contrast and temporal light stability, and yet they all produce visually stimulating environments that enhance the architectural expression of interior space. In considering this diversity of architectural examples, our goal is to define the perceptual characteristics that distinguish them and determine what this can tell us about the role of contrast and luminous diversity in the visual performance of interior space. While the notion of perceptual 'quality' is, admittedly, a difficult element to quantify due to its subjective nature, we believe that there are measures that can evaluate the compositional impacts of contrast and luminance diversity and help inform architects about their varied effects over time. Although we have no intention of prescribing

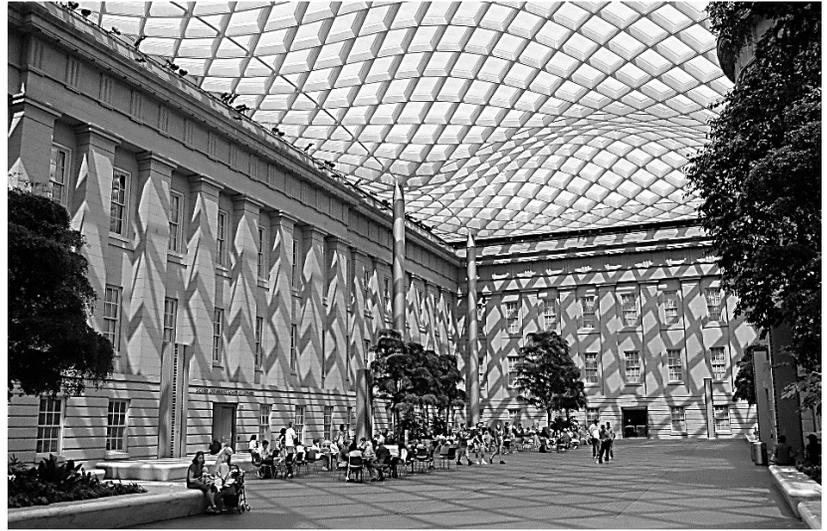


figure 1 Kogod Courtyard by Norman Fosterⁱ



figure 2 Church of St. Ignatius by Steven Hollⁱⁱ

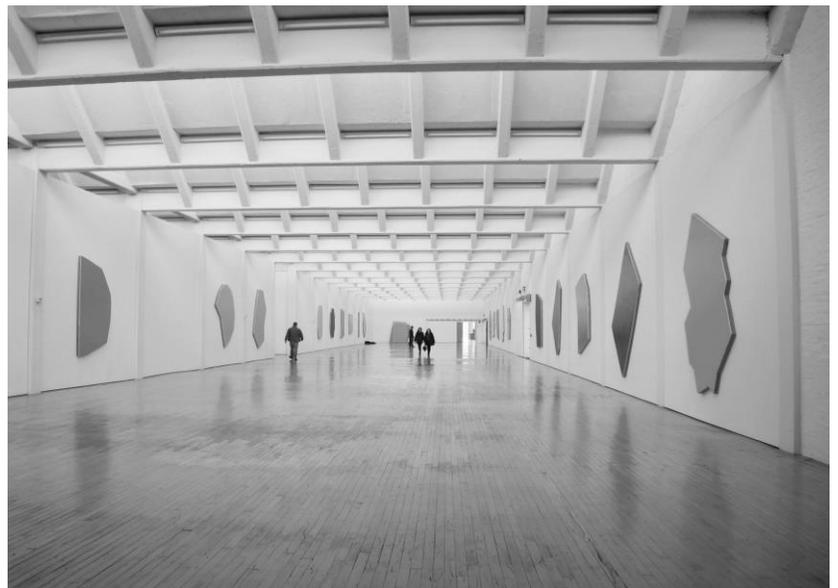


figure 3 Dia Beacon Museum by Steve Irwin and Open Officeⁱⁱⁱ

universal recommendations for contrast or luminous diversity, establishing a method for quantifying these compositional effects will provide architects a tool for comparing design options and contextualizing those options within a relative scale from high to low contrast or dynamic to static. If we can measure and compare the impacts of contrast and luminous diversity over time, we can help architects to communicate their aesthetic objectives more comprehensively and choreograph the dynamic visual effects of a space to meet their intended design goals.

Through ongoing work conducted in the Laboratory for Performance-Integrated Design (LIPID lab) at the Ecole Polytechnique Federale de Lausanne, we are developing dynamic metrics for the measure of contrast and daylight composition in architecture. A more complete description of these metrics is published elsewhere [4] [5] but we will briefly introduce Spatial Contrast here to illustrate the potential simulation-based application of these measures and their ability to compare architectural spaces for relative daylight-driven visual effects. Annual Spatial Contrast (ASC) is an image-based metric that assesses the strength of luminous contrast and luminous diversity across the year. When applied to an annual set of renderings, which account for a symmetrical distribution of hourly and monthly instances, we are able to measure where, within a given view, contrast is most predominant and how this compositional effect varies under dynamic sky conditions. As a result, we can effectively compare spaces that vary in the distribution and choreography of daylight.

In digital image analysis, there are two types of measures that are commonly used to quantify contrast: those that rely on global measures and those that rely on local measures. Global measures most often rely on two single points of extreme brightness and darkness, taking into account the difference in maximum and minimum values [6]. Other methods account for average luminance, or the standard deviation of values [7] [8] and while these global contrast measures provide a single comprehensible value, they cannot effectively predict perceived contrast between two images that vary in composition [9].

Local contrast values were developed to overcome the limitations associated with global measures by quantifying the effect of composition on contrasting areas of brightness and darkness. Included within this group of measures are methods that measure spatial frequencies in the Fourier domain [10], and those that calculate the difference between a single pixel and a surrounding region or neighborhood [11] [12] [13]. The authors have developed the term Spatial Contrast (SC) to describe the sum of local variations across a rendering. Spatial contrast draws on a simplified version of two existing neighborhood measures [12] [13] and computes the cumulative sum of localized contrast values, or 'boundaries' across an image, which represents a single instant of time (figure 4). Annual Spatial Contrast (ASC) then computes the sum of spatial contrast across all annual instances to produce an annual profile of contrast for a given view. Figure 5 shows seven hourly instances for a top-lit space with corresponding spatial contrast plots to illustrate how solar position can dramatically alter perceived contrast within the space. Spatial contrast values can be plotted spatially, to show *where* contrast is the strongest, and temporally, to show *when* that contrast varies over time. Temporal plots showing annual variation will be presented in figures 7,8, and 9.

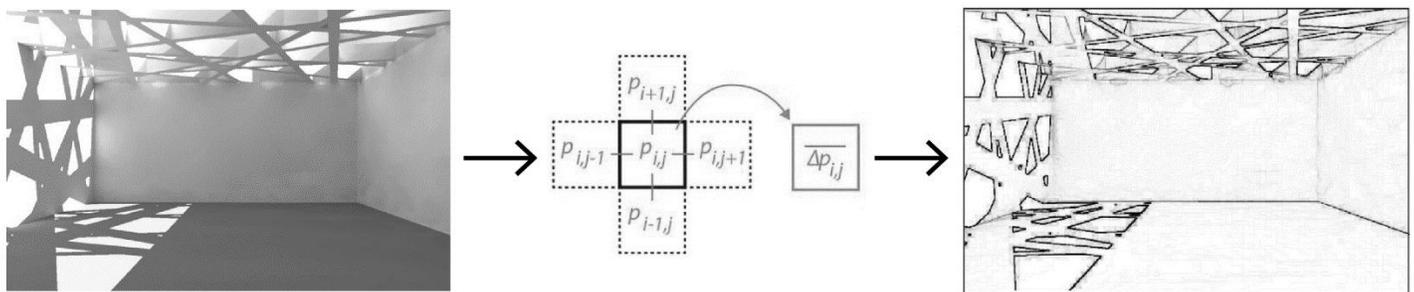


figure 4 Spatial contrast is calculated for each pixel on the left to produce the representation of contrast boundaries on the right.

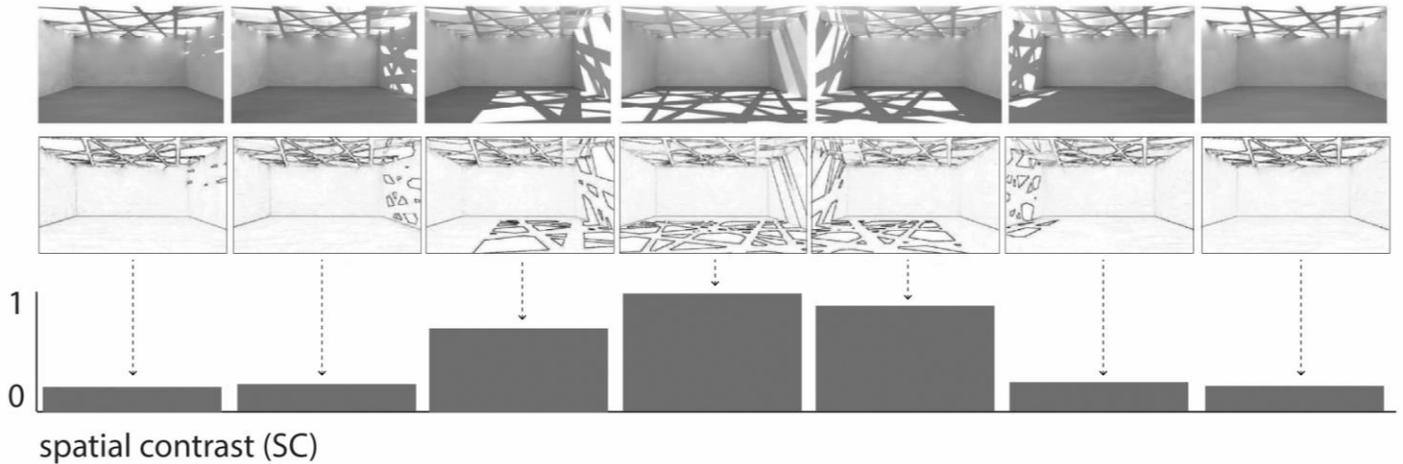


figure 5 Spatial contrast for 7 hourly instances, with values normalized from 0 to 1 to show how solar orientation can increase the strength of visual effects over the course of the day.

A full proof-of-concept study can be found elsewhere [4] [5], but we will show three case study spaces here which represent opposite and intermediate points in the contrast spectrum (figure 6). Similar to the Kogod Courtyard, shown in Figure 1, case study one was modelled to represent a highly contrasted and variable interior daylight environment with an open roof structure that casts dynamic and articulated patterns of light and shadow down onto the walls and floor. As shown in figure 7, case study one generates a high degree of spatial contrast throughout the year. The temporal map in figure 7b shows a peak between 10am and 3pm in the summer months when the sun is directly overhead, while the false-color image in figure 7c, shows thick red lines where spatial contrast is most consistent, highlighting the roof structure as the most redundant source, with secondary accumulations on the floor and walls.

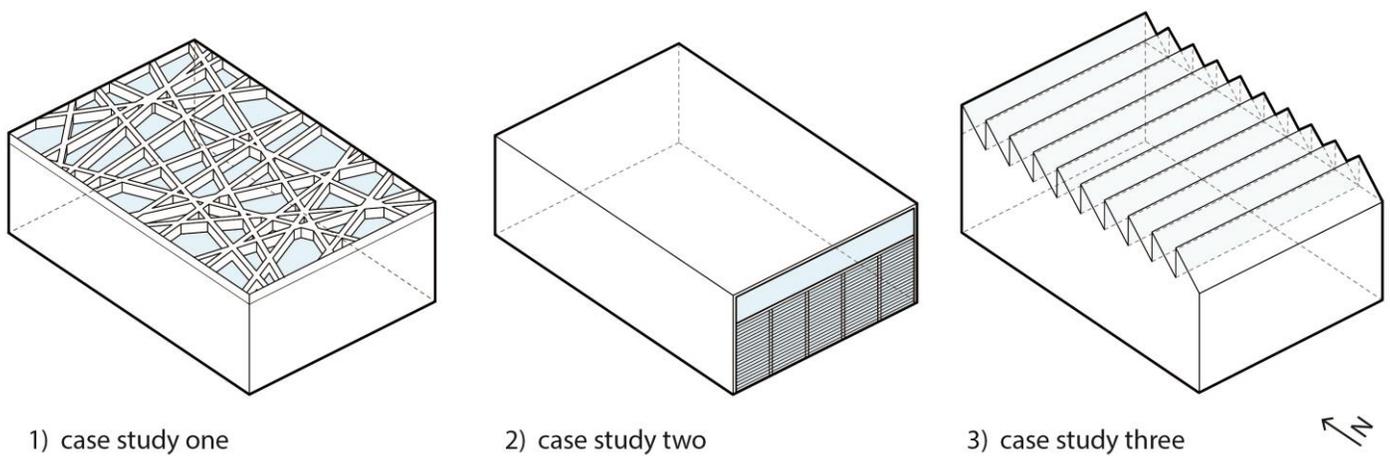


Figure 6 Case studies one, two, and three

Case Study two, shown in figure 8, represents a more traditional side-lit daylight strategy with a clerestory window above and louvered screen below which creates varied effects across the year depending on the time of day and position of the sun. The temporal map in figure 8b shows high spatial contrast between October and March, with low-to-moderate levels throughout the summer months of the year. The location of these effects can be seen in the false-color image in figure 8c, which shows the accumulation of contrast on the walls and floor closest to the exterior glazed wall.

Case study three, similar in effect to the Dia Beacon Museum in Figure 3, contains a series of north-facing roof monitors that emit diffuse daylight down into the interior space. Across most of the day and year, case study two achieves uniform luminance distribution with discreet moments of increased contrast that occur when direct sunlight penetrates the roof monitors in the early morning and late afternoon, as seen through the renderings in Figure 9a. We can see these low spatial

contrast values reflected in the temporal map in figure 9b and false-color image in figure 9c, with slight peaks in the mornings and afternoons during the summer months. This shift is due to low solar altitude angles in the morning and late afternoon, which allows direct sunlight to penetrate the skylights and cast shadows across the walls and floor.

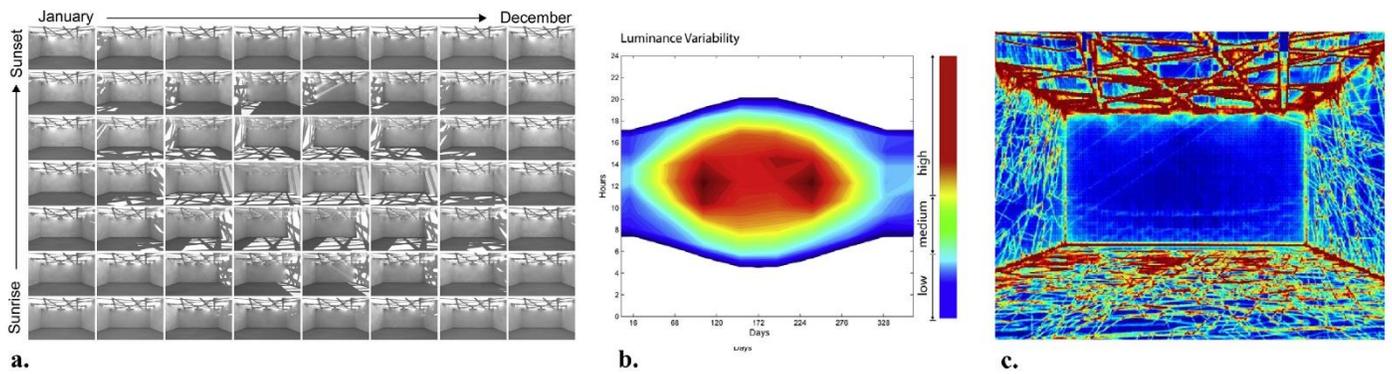


figure 7 Spatial contrast results from case study one.

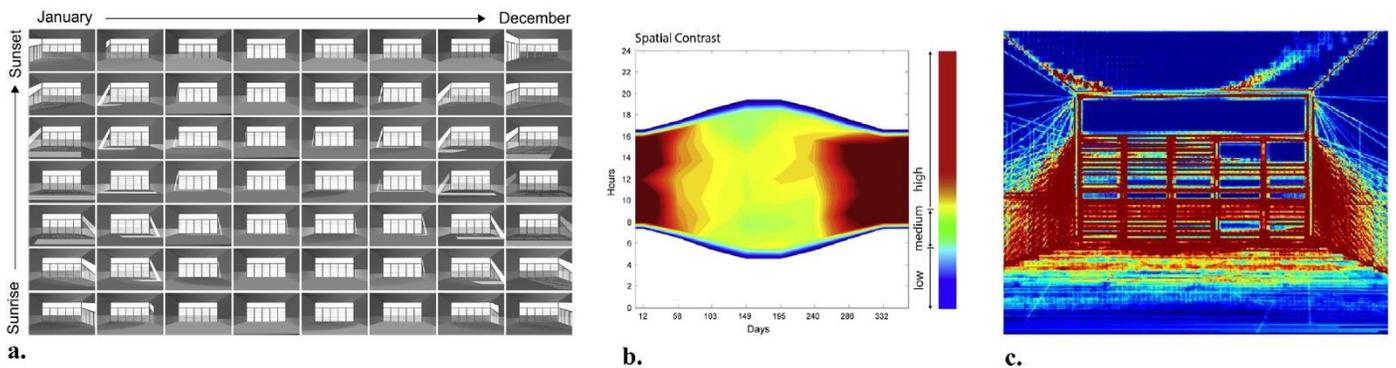


figure 8 Spatial contrast results from case study two.

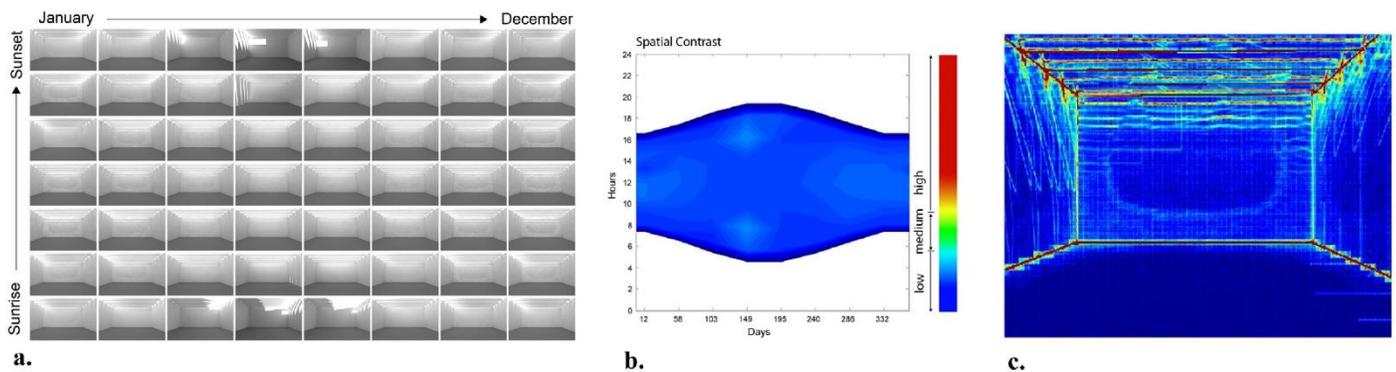


figure 9 Spatial contrast results from case study three.

This research raises an important set of issues for architects and daylight designers. How do we leverage perceptual performance indicators against those task-based illumination and visual comfort metrics that dominate the field of daylight performance analysis? To further develop and validate these new metrics, we will expand the set of case studies presented in the proof-of-concept study [4] [5], three of which were shown here, to include a set of detailed existing architectural spaces. Using this expanded catalog of spaces, we will conduct an experimental study to validate the relationship between human perceptions of contrast, existing, and proposed metrics. After validation, these novel metrics will then be integrated into a software package called Lightsolve, created at MIT and currently under development at EPFL, alongside dynamic illumination, comfort, and health-based metrics as part of an integrated tool to assess human needs in daylit architecture

[14]. These new annual metrics will help to communicate information about the spatial and temporal quality of daylight, providing architects with a tool for comparing the magnitude of visual effects within architecture. From a simple analytical tool that illustrates the dynamic conditions of daylight, this work challenges the use of existing task-based illumination and comfort metrics in a variety of programmatic conditions where contrast-based visual effects are not only accepted, but celebrated.

References

- [1] S. Holl, *Luminosity / Porosity*, Tokyo: Toto, 2006.
- [2] M. A. Steane and K. Steemers, *Environmental Diversity in Architecture*, New York: Spoon Press, 2004.
- [3] S. Holl, *The Chapel of St. Ignatius*, Princeton: Princeton Architectural Press, 1999.
- [4] S. Rockcastle and M. Andersen, "Measuring the dynamics of contrast & daylight variability in architecture: A proof-of-concept methodology," *Building and Environment*, pp. v 81, 320-333, 2014.
- [5] S. Rockcastle and M. Andersen, *Annual Dynamics of Daylight Variability and Contrast: A Simulation Based Approach to Quantifying Visual Effects in Architecture*, London: Springer-Verlag, 2013.
- [6] A. Michelson, *Studies in Optics*, Chicago: University of Chicago Press, 1927.
- [7] P. King-Smith and J. Kulikowski, "Pattern and Flicker Detection Analysed by Threshold Summation," *Journal of Physiology*, vol. 249, no. 3, pp. 519-548, 1975.
- [8] A. Calabria and M. Fairchild, "Perceived image contrast and observer preference II. Empirical modelling of perceived image contrast and observer preference data," *The Journal of Imaging Science and Technology*, vol. 47, pp. 494-508, 2003.
- [9] G. Simone, M. Pedersen and J. Y. Hardeberg, "Measuring perceptual contrast in digital images," *J. Vis. Commun. Image R.*, vol. 23, no. 3, pp. 491-506, 2012.
- [10] R. Hess, A. Bradley and L. Piotrowski, "Contrast-coding in amblyopia. I. Differences in the neural basis of human amblyopia," in *Proceedings of Royal Society of London Series B (217)*, London, 1983.
- [11] Y. Tadmor and D. Tolhurst, "Calculating the contrasts that retinal ganglion cells and LGN neurones encounter in natural scenes," *Vision Research*, vol. 40, no. 22, pp. 3145-3157, 2000.
- [12] A. Rizzi, G. Algeri, D. Medeghini and A. Marini, "A proposal for contrast measure in digital images," in *Second European Conference on Color in Graphics, Imaging and Vision*, Aachen, 2004.
- [13] e. a. Matkovic, "Global Contrast Factor - A New Approach to Image Contrast," in *Proceedings of the First Eurographics conference on Computational Aesthetics in Graphics, Visualization and Imaging*, Girona, 2005.
- [14] M. Andersen, A. Guillemain, M. Amundadottir and S. Rockcastle, "Beyond illumination: An interactive simulation framework for non-visual and perceptual aspects of daylighting performance," in *In Proceedings of IBPSA 2013*, Chambéry, 2013.

ⁱ AgnosticPreackersKid, 'The Kogod Courtyard' May 29, 2010 via Wikimedia, creative commons license

ⁱⁱ Joe Mabel, 'Chapel of St. Ignatius' November 30, 2007 via Wikimedia, creative commons license

ⁱⁱⁱ Augie Ray, 'Imi Knoebel's 24 Colors' November 9, 2013 via flickr, creative commons license