Materiality & Light: Case Studies Exploring Architectural Surfaces Informed by Light Behavior

Rachel Dickey

University of North Carolina Charlotte, United States
rachel.dickey@charlotte.edu

Abstract. This paper outlines three case studies that explore the relationship between form, material behavior, and light performance. Each case study appropriates methods of computational analysis, parametric design, and digital fabrication to construct directed light fields and patterns from architectural surfaces in public spaces. Each project explores how controlled conditions of materiality and light phenomena may provide opportunities to reengage the physicality of human experience by generating effects that attempt to enhance human interaction and spatial perception.

Keywords: light behavior, form, performance, ray-tracing, digital fabrication, parametric design

1 Introduction

Zoom meetings, social media identities, delivery robots, and pocket-sized computers, exemplify a few of the many ways technological advancements increasingly disconnect our bodies and experiences from our physical world. With screen-based activities consuming areas of work and recreation, there is an increasing "*de-realization*" and "*de-materialization*" of the human experience (Bressani, 2013, 324). In response, this paper outlines three case studies that explore how controlled conditions of materiality and light phenomena may provide opportunities to reconsider and reengage the physicality of human experience. The projects do not try to solve the problem of disembodiment generated by our technologies but rather provide methods for exploring ways to rethink and revisit the relationship between sensation and the physical environment.

Each of the case studies computationally investigates the relationship between architectural form and performance and appropriate methods of parametric design and digital fabrication to construct directed light fields and patterns from architectural surfaces in public space. More specifically, the studies involve analyzing and evaluating the performative conditions of material-informed forms relative to their lighting effects in order to drive procedures for design and fabrication. The intent is to provide an opportunistic approach to design research in order to create spatial and atmospheric outcomes that consider optical conditions and their effects on perception through an investigation of light.

1.1 The Affective Qualities of Light

Scientific study has proven exposure to bright light with specific spectral qualities affect our psychological, physiological, and biochemical functions and overall health (Wirz-Justice, 2023). In art, the presence or absence of light has been used to evoke emotions and generate experiences. In architecture, contemporary discourse around atmospheric qualities and affective qualities including the work of authors Tonino Griffero and Gernot Böhme outlines ideas of embodiment and re-engaging the senses by which light can play an essential role. Drawing upon these multifaceted concepts, the work outlined explores light as part of an embodied experience and studies opportunities for alternative visual effects in the design of architectural surfaces.

1.2 Light as a Material

Architects have had a long-standing motivation to explore conditions of light through the arrangement of materials, with a history dating back to the construction of Stonehenge to the present day. Elisa Valero Ramos in her book, *Light in Architecture*, outlines the notion of light as an intangible yet enduring and effective material, when she writes:

> *Architecture uses another 'material,' which is fundamental for the construction of space and which is not listed in the technical specifications. That material is light. Light–natural light–is a very special component of the architect's palette of 'materials.' It is the only one not subject to the force of gravity; it is free, it changes constantly, bringing about shadows and colours in perpetual movement; it does not age; and it is always original*. (Ramos, 2015)

Additionally, Henry Plummer in his book, *The Architecture of Natural Light*, also describes light as a building material and highlights the importance of its effects, describing how considerations of light in architecture provide opportunities for more interaction between built and natural worlds, elevating humanistic concerns beyond the mere provision of shelter.

This paper elaborates on the notion of light as a material by generating light-based patterns along architectural surfaces. More specifically the projects investigate caustic light patterns produced by fields of light rays reflecting and refracting off of curved surfaces. Francois Mangion and Shuchi Agarwal likewise explore similar light-based pattern effects in their research (2013) in order to inform building scale forms and spaces. Additionally, Thomas Kiser explores how geometry influences caustics and light behavior (2013). However, the research in this paper differs from these references in its exploration of caustics and light patterns which involve architectural surfaces that directly engage experiential qualities at human scale. The work also uses computational design, analysis, and actualization of such ideas through material study and the development of fabrication strategies. As explained in Neri Oxman's *Additive Manufacturing of Optically Transparent Glass* paper, "precomputed shapes can be generated with caustics by modeling light transmission to control the patterns and form desired shapes" (2015). However, the case studies presented here explore such effects through the assembly of customized panels rather than additive manufacturing. Additionally, these studies provide feasibility for enhancing the experience of light through effects and patterns in architectural design.

2 Caustic Light Fields

The first case study titled, Light Fields, explores how light behavior can drive the conceptual agenda for a project by articulating conditions of visual experience through the design of light-informed surfaces. Light Fields is a permanent installation made of 500 unique panels sited in the University of North Carolina Charlotte Marriott Hotel and Conference Center lobby, which appropriates computational design and digital fabrication strategies in order to explore how architectural surfaces might channel essential environmental ingredients. The project is a permanent installation designed to create fields of light patterns on the wall solely by reflecting existing light in the space (Fig. 1 and Fig. 2). It involves the exploration of caustic effects produced by curved surfaces reflecting and refracting light rays in an attempt to provide a heightened awareness of light through form directed patterns.

The project uses the bending properties of custom-cut PETG panels with mylar reflective film, variably rotating and interlocking in a gradient field configuration. Each panel directs and reflects light from the existing interior fixtures to produce a range of caustic effects. Through parametric design and analysis, the research and design team optimized the caustic lighting effects and patterns across the neighboring surfaces delineating zones of space through light. This was accomplished by exploring variability in the bending radius of the panel and variable reflectivity of materials relative to existing light orientation using ray-tracing scripts produced with Ladybug, a plugin for Grasshopper, paired with V-Ray in order to both visualize the field of light rays as both line-based drawings and as rendered images (Fig. 3). The variable curvature of surfaces considered the bending material properties in order to analyze how the bending radius affected light patterns. For instance, a tighter bending radius produces more caustic effects since the light rays are directed to the center of the surface curvature. While a flat panel evenly reflects light rays, a curved panel allows the network of light rays to intersect one another.

The next steps of design involved the exploration of various panel configurations. Such configurations of panels were explored parametrically by gradually rotating each panel to direct the light rays in various directions. By integrating a rendering engine in the process, various light patterns were studied to understand how rotating panels and intersecting panels generated different results.

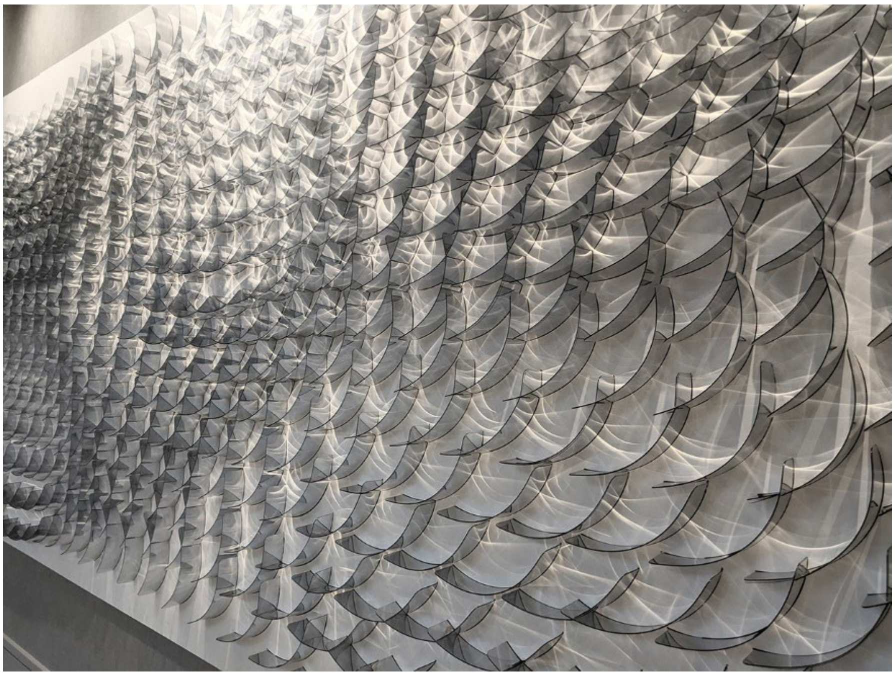

Figure 1. Image of Light Fields installation reflecting light from existing interior lights. Source: Studio Dickey, 2021.

The fabrication of the installation involved design for manufacture strategies to ensure anchoring and assembly of each panel. The panels were made of a laser-cut PETG with a mylar reflective film thin enough to allow for bending. Then each panel held its curved form by inserting it into an MDF board with CNC-milled curved slots at their designated location. Due to the intersecting conditions of the panels each having a unique location and size, a custom script was generated to create a notching system where the parts could slide together and interlock. The script included an indexing system accounting for the order of assembly by allowing each part to incrementally interlock with each additional panel without having to adjust or remove any panels along the way. This involved a loop incrementally designating notches at the top and bottom locations of each panel. Likewise, the script included numbering and labeling in order to index each of the 500 unique parts with specific notched conditions at panel intersections.

Figure 2. Detailed image of scripted notching panels inserted into CNC milled MDF.
Source: Studio Dickey, 2021.

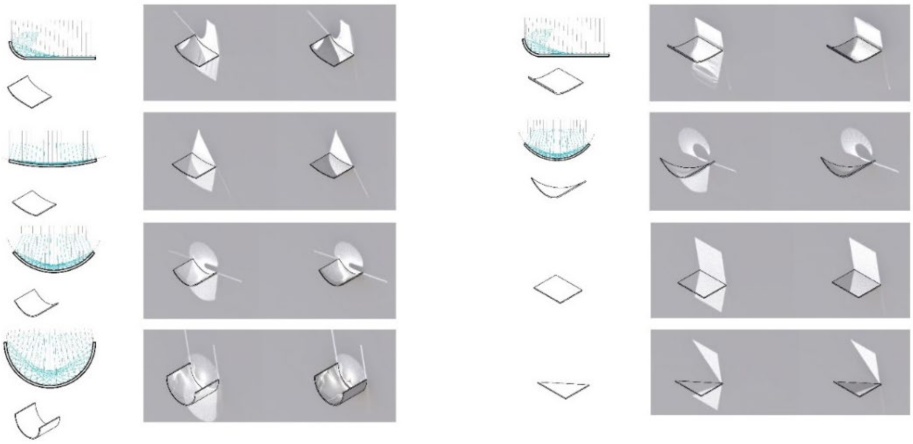

Figure 3. Ray tracing light drawings and rendered patterns reflected from surfaces with variable bending radii. Source: Studio Dickey, 2020.

3 Caustics Delineating Protective Space

The second case study was a rapid response public intervention, designed based on Covid-19 social distancing measures, which involves parametrically designed room-sized face shields. Designed and built within two months in 2020, the Covid Confessionals installation is a rapid response public intervention that provides spaces for interaction during a time of distressing social isolation. Made of PETG backed with dichroic film the installation casts fields of color and large-scale daylit caustic patterns on the ground plane in public space. Overall, its various configurations provide conditions for social exchange and playful interactions.

It architecturally manifests distancing measures using the CDC's six-foot metric of separation as the modular basis of its design. It parametrically appropriates tessellating hexagon grids with curves constructed from six-foot radius circles to assemble multiple configurations to promote safe social distancing with color fields of light rays designating safe interaction zones in public space. Additional parameters involved variability of the height of shields to provide spaces for sitting and standing. Subtractive operations in the script provided a means for removing openings along the shields for fluid circulation between modules. Figure 4 depicts physical models constructed from these design variables.

Fabrication strategies for the installation drew from the geometry of interpolated spline curves constructed and derived digitally by low-degree polynomials between points and translated physically by bending dichroic

PETG panels anchored at fixed points along CNC bent members (Fig. 5). Structurally the dichroic shields were supported by a prefabricated conduit frame and off-the-shelf deck blocks for foundation support due to the fast-paced nature of the project being constructed within two months in response to the pandemic.

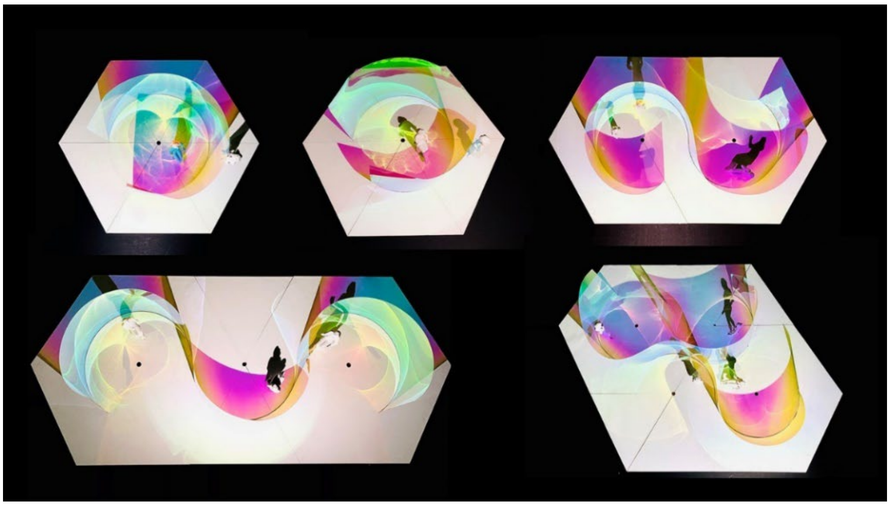

Figure 4. Physical scale models developed from parametric hexagon grid tessellation and curves constructed 6-foot radius circles. Source: Studio Dickey, 2020.

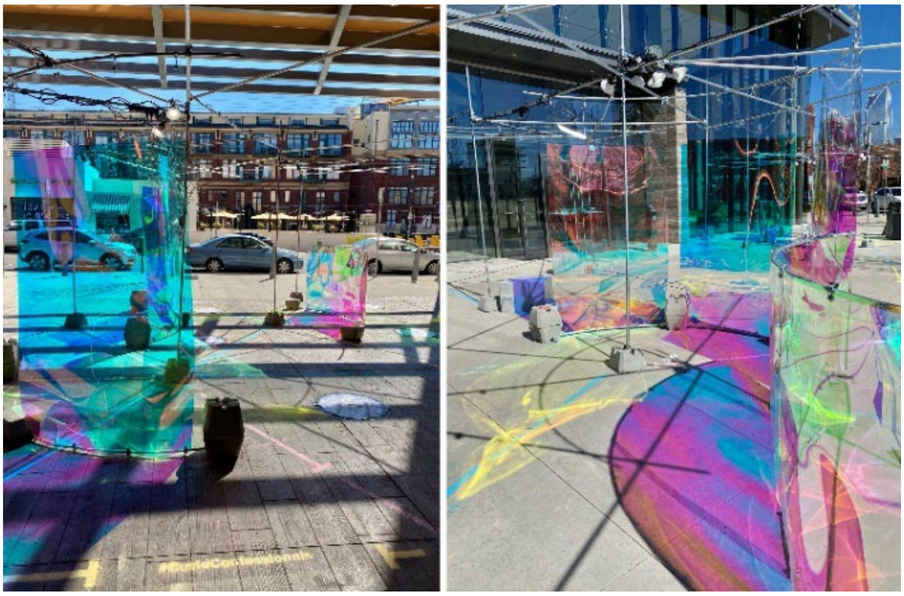

Figure 5. Installation with dichroic film casting caustic light patterns and raking colorful shadows. Source: Studio Dickey, 2020.

4 Light-informed Ruled Surface

The third case study titled, Gold Rush, explores reflective curved surfaces suspended within a dynamic ruled surface structure (Fig. 6 and Fig. 7). Each of the 480 panels bends and anchors across a frame of rotating linear wood members connected uniquely in a position to form a networked curved surface. The frame spacing and panel orientation are intended to allow for the play of light effects across the dynamic surface situated along the public transportation thoroughfare walkway.

The development of the project involved the exploratory study of material behavior through variable bending radii of the panels and variable orientation. The variability allowed for the investigation of various ways of delineating space through dynamic reflection and varying transparency based on panel orientation. The team studied the visual effects through ray-tracing studies using Ladybug to understand the range and direction of reflective light off of the curved panels. The fabrication procedures extracted position information from parametrically rotating linear structural members in order to fasten and orient them in position with painted steel angle connections. Through analog and computational study, the project tries to dematerialize the limits of space providing porosity and layers of light as an additional material condition.

Figure 6. Installation with reflective gold panels suspended within a structural ruled surface. Source: Studio Dickey, 2023.

Figure 7. Light installation along Rail Trail in Charlotte, NC. Source: Studio Dickey, 2023

5 Conclusion

Each case study works across physical and digital domains, exploring material properties and resulting light phenomena as inputs for computational design. The light behaviors reflected from surfaces and material constraints act as performance metrics for form generation and fabrication. The results of each study provide spatial conditions for human interaction re-engaging the physicality of experience.

This collection of work invites us to interact with the material conditions of our physical world by activating architectural surfaces. It examines how light and darkness, brightness and contrast, and pattern and effect create change in space and atmosphere. Antoine Picon describes similar relationships to experience and materiality when he writes:

> *Materiality usually designates the material dimension of a phenomenon, a thing, an object, or a system in relation to human thought and practice. […] It characterizes the type of rapport that we, humans, maintain with materials, and, more broadly with the physical world around us with the phenomena, things, and objects that we perceive through our senses as fundamentally material.* (2020)

Materiality moves ideas to a physical reality where people interact with our imaginaries, experiences, and practices (Picon 2020). The case studies presented avoid a building science approach and instead, the work asks, how might the material conditions of the environment cause an awakening or momentary disruption that alters spatial perception? In response, these materials studies attempt to encourage alternative forms of engagement with the built environment mediating between our bodies and the world around us.

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References

Griffero, T. (2010). Atmospheres: Aesthetics of Emotional Spaces. Routledge.

Kiser, T., Eigensatz, M., Nguyen, M.M., Bompas, P., & Pauly, M. (2013) Architectural Caustics: Controlling Light with Geometry. Retrieved August 2, 2023, from https://www.researchgate.net/publication/279358928

Klein, J., Stern, M., Franchin, G., et al. (2015)Additive Manufacturing of Optically Transparent Glass. In 3D Printing and Additive Manufacturing. September 2015, (pp. 92-105). Mary Ann Liebert, Inc. http://hdl.handle.net/1721.1/98880

Mangion, F., & Agarwal, S. (2013). Caustic Architecture. Retrieved August 2, 2023, from http://www.formakers.eu/project-1051-francois-mangion-and-shuchi-agarwal-caustic-architecture

Plummer, H. (2009). The Architecture of Natural Light. The Monacelli Press.

Ramos, E. (2015). Light in Architecture: The Intangible Material. RIBA Publishing.

Picon, A. Matter, Materials, Materiality. In The Materiality of Architecture. (pp.4-20). University of Minnesota Press.

Wirz-Justice, A., Andersen, M., Kenderdine, S., & Bini, G. (2023). Lighten-Up: On Biology and Time. Exhibition at EPFL Pavilion Lausanne. May 24 - July 30, 2023. https://epfl-pavilions.ch/exhibitions/lighten-up