

Y. Ikeda, C. M. Herr, D. Holzer, S. Kajjima, M. J. Kim, M. A. Schnabel (eds.), *Emerging Experience in Past, Present and Future of Digital Architecture, Proceedings of the 20th International Conference of the Association for Computer-Aided Architectural Design Research in Asia CAADRIA 2015*, 000–000. © 2015, The Association for Computer-Aided Architectural Design Research in Asia (CAADRIA), Hong Kong

UNDERSTANDING LIGHT IN BUILDING SKIN DESIGN

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Abstract. This paper describes a design approach for discerning solar gain and assigning appropriate external shading devices. The approach includes a macro analysis locating where and when the building receives direct sunlight and locating desired interior daylighting; along with a micro analysis of how folded sun-shading motifs filter or block direct sunlight. The approach uses a collaborative analytical workflow with feedback from virtual and physical simulations informing design explorations. This iterative, reciprocating process is illustrated by student efforts to design shading structures for a building based on incident solar radiation. Designers begin with cutting and folding paper study models, then lasercut 2D tessellation patterns to create sculptural shading screens to be examined with a heliodon. Physical daylighting modeling reveals aesthetic opportunities to develop with parametric design. Motifs are then digitally modeled and analysed for shading effectiveness. Analysing the solar radiation of simple motifs helps beginners learn the software for subsequent urban situations. The efficacy of these simulations is discussed along with ways that the results could be interpreted to initiate design decisions for a building skin.

Keywords. solar simulation; collaborative design; folding surfaces; physical and digital simulation.

1. Introduction

Architects need to consider and integrate multiple factors, particularly when seeking to use performance simulation data to inform building design decisions. This means architects frequently must negotiate part-to-whole relationships--both the physical components and systems being designed (Lynn, 2008) and also the design problems which are addressed. While such problems may be divided into a series of parallel tasks, bringing individual results back into a larger design proposal can require many difficult trade-offs. To meaningfully engage aspects such as material constraints, digital form-making and environmental consequences, it is important to structure how a team examines these factors.

This paper explains an approach for layering design considerations within the pedagogical framework of a course for third and fourth-year architecture students. Three teams worked in parallel on folding surface design, energy analysis and material fabrication studies, with each informing the larger group. The course title 'Digital Material' belied a broad agenda to design and prototype a facade shading system created with folded sheet materials, for retrofitting existing structures. In the semester-long course, students examined how folding and bending surfaces could provide visual effects while blocking unwanted solar heat and glare. The purpose was to strengthen skills in parametric design and simulation methods to address design complexities involving radiative heat and visible light as well as material characteristics.

Six students within a larger cohort chose to pursue this exercise. An existing rectilinear building was chosen as the base for applying the external shading design system. This building provided a useful site for testing as it has facades facing close to due north, south, east and west and its existing external sunshade system could be observed.

To manage the design process, a series of sub-tasks were introduced to students to address particular design aspects before facing the larger design problem. These elemental tasks were:

1. The design of concept panels made from folded paper and card.
2. The study of incident light and filtered light using a robotically controlled heliodon to physically simulate Sun paths
3. The parametric modelling of geometrically-related folded surface designs
4. The study of incident and filtered light using virtual solar simulations.
5. The fabrication of panel prototypes to explore materials at full-scale.

The focus of this paper is the solar simulations with both physical and digital tools (items 2. and 4. above) and their impact on the design outcomes.

The goal was that the simulations would contribute to the screen system refinement and result in a proposal tailored to the site's solar conditions.

2. Background

A building's exterior skin plays a critical energy-saving role as the threshold between interior conditions and the external environment. Hence, a variety of additive patterned shading systems have been designed to protect fully glazed façades from direct solar radiation. While noon-time Sun can be effectively shaded by horizontal overhangs, early morning and low afternoon sun hitting the east and west orientation facades requires more careful design because of the conflict between view and glare. Particularly for hot climates, it is a possibility to use shading devices, such as traditional mashrabiya shading screens, facing these orientations to protect the building from intense sunlight all year around to avoid overheating in buildings.

Methods for generating folding surfaces and existing architectural shades were studied to understand how folding surfaces could mediate light and magnify the cooling effects from self-shading. These served as a prelude for physical and virtual exercises for understanding how user perceptions of the screens are affected by incident solar radiation.

2.1. FORM AND LIGHT EXPLORATION THROUGH ORIGAMI

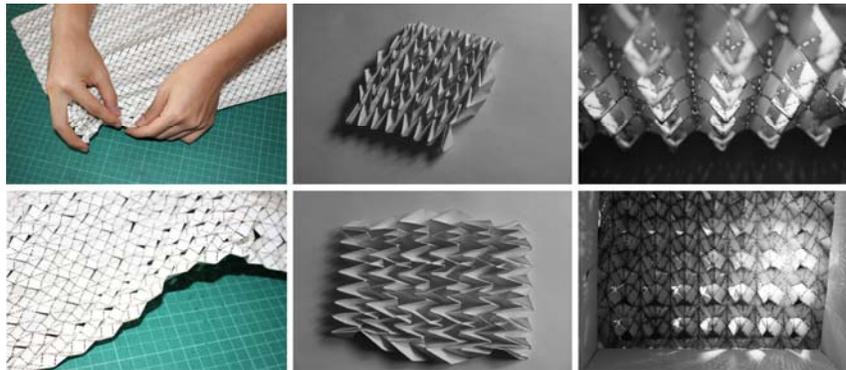


Figure 1. Design and lighting studies with folded paper models.

Many designers are attracted to origami because of the inherent efficiency of creating 3D form from a single folded surface. Paul Jackson (2012) introduces basic folding patterns in an open-ended way that invites designers to explore possibilities. Nergiz Yiğit (2004) provides an overview of the history of origami in product and furniture design and reviews processes for folding

several materials. In the digital realm, Daniel Piker's Rhino Grasshopper plug-in physics modeller Kangaroo incorporates Hinge and Origami components that enable folding and Gregory Epps's Robofold system uses robots with magnets to make curved folds in sheet metal. In parallel, Epps developed a Grasshopper folding modular design tool King Kong and a Curved Folding repository (2014).

The relationship between folded surfaces and visual effects may be understood by examining daylighting models under controlled lighting conditions. Cardboard models constructed of the desired opacity and reflectance, with apertures and geometry to scale, can provide a good visual approximation of daylighting effects. Because of the subtle visual effects caused by variable light on folded materials, qualitative observations can be valuable for understanding of how the patterns in light are perceived by inhabitants. The ability to quickly adjust them and see the results makes physical models an important complement to digital methods. Cutting and folding paper sheets (Figure 1) give insight into the shading performance of folded patterns with direct, low-cost techniques. Initial studies were first done with a single material of thin white cardboard to focus on how form affected the results. Subsequent studies could examine how material properties such as colour, reflectivity, transmissivity and emissivity can affect the thermal performance of a shading system.

2.3. EXAMPLES OF SHADING WITH FOLDING SURFACES

Folding surfaces are relevant to building design performance for their ability to self-shade. As a model, the ribs of the barrel cactus protect its skin against incident solar radiation through casting shadows (self-shading) (Lewis and Nobel, 1977), showing that an undulating skin can create rhythmic gradations of light and dark while also preventing overheating during the hot desert summer. In a similar way, the building facade of Kuwait University College of Education is predicted to reduce 82% of the solar heat gain (Aksamija, 2013).

Fixed shading forms can be designed for the hottest periods of a building's occupation, kinetically-activated folding components can adapt to changing climatic conditions. Umbrella-like modules on the Al Bahr Towers demonstrate how interactive facades can maximize views by shading areas of the tower only when needed. (Oborn, 2014)

3 Lighting and solar radiation analysis in the Design Process

To improve how buildings accommodate human habitation, designers need to define crucial performance criteria. Oxman (2008) describes performance-

based models in architecture as those that exploit building performance simulation to modify geometrical form with the objective of optimising a design. In this case, lighting quality and solar radiation data were the key design drivers for the shading system design. The broad goal was to reduce undesirable summer direct solar heat gain while balancing usable daylighting, visual comfort and aesthetic interest.

Our pedagogical framework employed complementary accessible methods to drive design decision-making. Physical and digital solar simulation platforms were introduced to reveal the dependencies inherent with the use of simulation tools for qualitative and quantitative environmental performance. Specific feedback (such as perceptive visual beauty; interplay of light/dark/gradients; relative area of shaded regions and relative incident solar radiation) from these simulation tools can be an integral part of an informed design process. The qualitative information from physical light studies and quantitative results from digital simulations can improve understanding of the consequences of complex patterning, driving design refinement. (Khorasgani et al., 2014a).

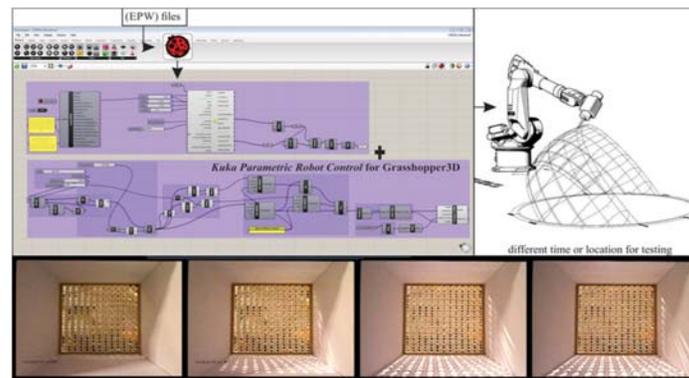


Figure 2. Robothermodon programming and interior of a screen tested on the platform.

3.1. PHYSICAL SIMULATIONS.

To enhance understanding of the mutual relationship between surface geometry, interior lighting quality and exterior appearance, we used a robot-driven heliodon, Robothermodon (Khorasgani et al., 2014b). It can simulate the Sun's movement (relative to the Earth's rotation and elliptical orbit) through any day of the year, in any location. Once programmed, it provides a user-friendly interactive platform for designers to visualize the interaction of moving sunlight and the physical form of a façade prototype. Lighting simulation with the Robothermodon offers direct visual information to designers

(Figure 2). Designers can visualize the impact of surface undulations, complex topologies, aperture position and shape on patterns of propagated light on the surfaces behind the façade prototype, while simultaneously observing self-shading on the screen exterior. As moving shadows can be captured on videos, designers can compare results before and after modifications, leading to a better understanding of natural lighting as a dynamic phenomenon. Such a platform is accessible for investigating the affective qualities of incident light. It enables rapid feedback on designed surfaces by simply attaching sample façade models to the existing platform. Direct and interactive visualization of lighting in the laboratory helps improve understanding of the complex phenomenal effects.

3.2. DIGITAL SIMULATIONS

The physical tests became the input for more rigorous formal exploration; the basis for geometric modelling and analysis with digital tools. The class used a Rhino / Grasshopper plug-in Ladybug (ref) for the climate visualization and digital solar simulation. It was chosen due to its intuitive and efficient nature in analysing radiation on parametric forms. A user-friendly tool suits the early stage of design when users need rapid access to information about alternative forms.

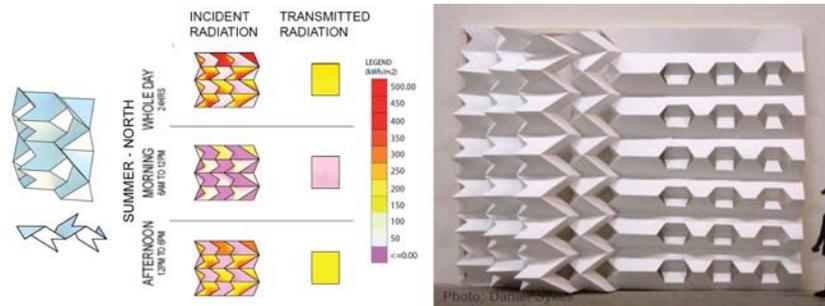


Figure 3. Micro-scale design studies showing digital model and solar analysis from Ladybug with folding transition panel.

The students modelled the 3D forms of simple shading pattern motifs and tested them for shading effectiveness, aggregating summer morning, afternoon and whole day values. They simulated the solar radiation on the surface of their folded screen modules, as well as that on a plane immediately behind the screen to measure incident solar radiation that passed through the porous screen. Analysing the solar radiation of simple folding motifs helps beginners in solar thermal analyses learn the software for subsequent more complex situations.

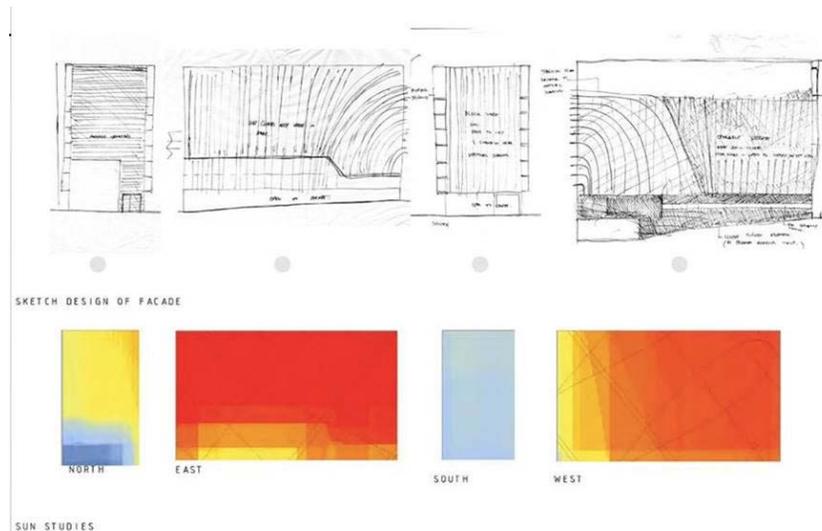


Figure 4. Facade sketches omit shading structures at cooler base, transition from horizontal on North to vertical on East and West following macro-scale radiation analysis (below).

Simultaneous to the motif analysis, the students did macro-scale simulations to discover the distribution of solar radiation falling on building facades facing east, west, south and north. They considered the context by modelling neighbouring buildings which cast shadows on the building, such as parts of the west and north facades (figure 4). Students analysed these facades for both summer solstice and winter solstice 8AM to 12PM and from 12PM to 4PM, as well as Total Radiation.

This macro-scale analysis informed broad strategies for façade design density and porosity. Subsequently appropriate shading patterns for the façade were selected and applied in a broader design schema. Working with partners who concurrently prototyped material assemblies, they adapted the patterns to create an expressive skin wrapping the building which provided shading where needed, responded to aesthetic proposals related to form and detailed prototypes, and opened the building's interior up to key views in the urban context.

3.3 CLASSIFYING RESULTS TO INFORM DESIGN DECISIONS

Careful classification strategies are needed to make rigorous statements about specific factors that influence the shading effectiveness. Examining one geometric parameter at a time reveals how changing the surface form affects light and incident radiation. Hence, variation matrices were intro-

duced to students to help classify patterns in regards to factors affecting incident and filtered solar radiation. Aligning solar radiation maps of design options with small changes effectively contained within changes of a single parameter allows a visual comparison of the effects relating to the particular parameter. This enables analyses of the effect of a single variable. For example, students compared how the depth of a folding module would affect incident solar radiation for the morning, afternoon and circadian Sun.

4. Discussion of results and lessons learned

Regarding the accuracy and efficacy of simulations, the lightweight analysis tools employed provide quick feedback during design exploration, so they can make a significant contribution and fundamentally change the design (Fisher, 2012). Most importantly, the simulations allow for comparative studies of design options and give an understanding of the proportional influence of particular design aspects on solar performance. While the simulation results appeared consistent to expected outcomes, verification with more sophisticated analysis tools would be a useful addition to the workflow. Naturally, expertise or time related to the accuracy and complexity of the tool would be required.

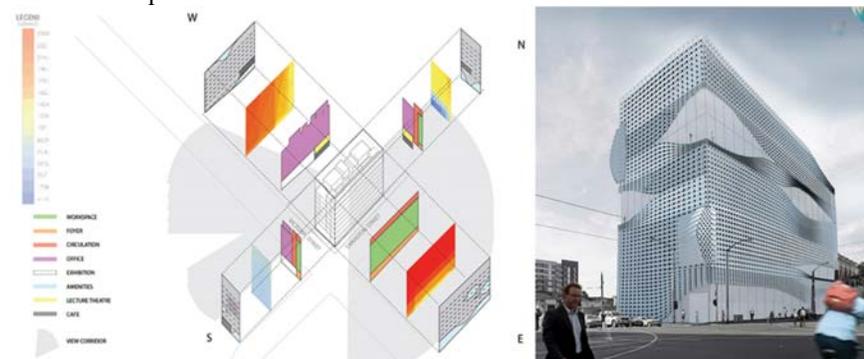


Figure 5. Interior functions, solar radiation and view corridors (l) shaped final façade (r).

The façade design exercise led to significant contributions but had some limitations. The students managed to bring their diverse efforts together into one coherent scheme, with comprehensive representations of a complex shading facade. Subgroups addressing overall folding design, solar analysis and fabrication, created an engaging learning experience as students took on different roles, brought varied expertise and were challenged in different ways.

The students were able to model a parametric system of components which covered the entire building. The result was a coherent design concept

based on material studies, but it was not successful in addressing the often conflicting requirements for shade and view. This belies difficulties in designing with such systems at a building scale. A parametric system might work well in many situations but there are likely areas for which the rules need to be adapted or broken. In particular, more sculptural projections for shading openings could have been studied, but were not attempted due to time constraints and the greater complexity of the required digital models.

5. Conclusions and further work

This teaching exercise addressed the use of simulation tools across scales and media. It integrated solar analysis studies to inform design of a building skin system. Accessible physical and digital simulation platforms were introduced, facilitating analyses including qualitative lighting visualization and solar radiation exposed to the building interior. Secondly, analyses at motif, room and building scales fostered understanding of the performance of proposed facade designs as well as the solar conditions of the case study building.

Constraints of time and student expertise limited integration of the simulation information into the broader design context. Verification of solar analysis results using high-fidelity simulations or light sensing equipment with the Robothermodon is envisioned for future design workshops, as this would allow further understanding of the limitations and inherent redundancies of the low resolution solar analysis.

This work highlighted particular characteristics of learning in a team setting. Design objectives and related performance criteria need to be articulated early, even if they change. Examining performance factors, such as shading, and incident radiant heat gain, immediately with direct physical methods opens designers' awareness to analytic factors. Reinforcing the understanding of these factors through repeated sequential efforts with digital tools enables honing of specialized skills.

Defining crucial parameters and then using a matrix to examine how each factor affects performance promotes understanding much more effectively than less targeted work. Coordinated parallel efforts allow small-group in-depth exploration and a broader overall development. Sequential layering of complementary studies allows designers to simultaneously develop skills and confidence while creating a common understanding for more sophisticated collaborative development. This explicit sequencing can be effective as both a pedagogical method and a professional collaborative design strategy.

Acknowledgements

This course lead by Nicholas Williams was offered by the Spatial Information Architecture Lab at RMIT University. Student authors were Larissa Aguilar, Gustaf Jervall Jeppsson, Vincent Lai, David Mendonça, Daniel Sykes, and Benjamin Tan.

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