Eclipsis System: Architectural Precedent and Digital Fabrication

Robert Dunay
Virginia Tech

ABSTRACT

Design research does not effectively fit the scientific model and does not enjoy traditional funding sources. The tendency to associate research with science, drawing the conclusion that objectivity is validated through quantitative data underpins much of academic culture. However, though scientific inquiry remains an effective instrument for unlocking secrets of the way things work, its capacity to embrace a holistic perspective remains questionable. Therefore, a particular role of a designer involves navigating between the perceived certainty of calculation, and situations of uncertainty, instability, and uniqueness embedded in artistic and intuitive processes.

Digital design and industrial fabrication have been the province of the automotive and aerospace industries for decades, and design fields have peered with envy at the precision of the structure/function relation that yields innovative performance. Alternative opportunities are now entering the consciousness of architects, changing the conception and operation of normative practice. Consideration of the possibilities of digital tools in architecture and their relation to fabrication and construction are overcoming the discrete specializations that typically govern the conventional building process. However there remains a nagging doubt regarding the trajectory of digital design and fabrication as integral tools capable of addressing contemporary issues. Speculative visualization depicting architecture as illustration, emboldened by the power of innumerable permutations has opened the door to vibrant imagery. But the gap between possibility and reality looms large. The graphic appeal of many of digital presentations is often presented without consequence of cost, maintenance, fabrication and assembly limitations. Protected from the realities of day-to-day entropy, they occupy a small corner of response to legitimate criteria. The project presented here attacks the difficult reality of the correspondence between material, technology, form and performance. As applied research, it employs considerable prototype development to produce a working building component. It has been validated through empirical testing and has triumphed in the rigorous setting of international competition.

A net-zero energy, solar house comprises the larger context. The concept of *Responsive Architecture* necessitated an adaptive building skin. The focus of this paper is the *Eclipsis* System, an innovative fenestration of laser cut, stainless steel shutter screens. Their primary function is maximizing daylight while controlling solar gain. The screens adjust to climactic changes and user requirements through automated systems that optimize energy consumption while offering architecture of delight. Shading, refracted light, privacy and ventilation are woven through a complex definition designed within Grasshopper, a graphic algorithm editor developed in conjunction with Rhinoceros®. Grasshopper, along with Visual Basics programming language allowed for the development of subtle complexity with extensive design versioning. Prototypes were developed through digital processes and tested empirically for performance. Water jet and laser cutting technologies were explored in relation to material characteristic and qualities and alternatives were re-routed back through the digital process to find a more refined geometry while increasing performance. Built and operated using industrialized processes, the *Eclipsis* System optimizes energy use, makes buildings more efficient, and improves the quality of architectural space.

INTRODUCTION

Design research does not effectively fit the scientific model and does not enjoy the traditional funding sources of other disciplines. The iterative, exploratory nature of design tends to make the process appear redundant and sometimes without focus while the technical rationality of the scientific method is accepted without question. The tendency to associate research with science, drawing the conclusion that objectivity is validated through quantitative data underpins much of university culture. However, though scientific inquiry remains an effective instrument for unlocking secrets of the way things work, there is nagging doubt regarding its capacity to embrace a holistic perspective, particularly in regard to the implicit values of human activities. Therefore, a particular role of a designer involves navigating between the perceived certainty of calculation, and situations of uncertainty, instability, and uniqueness embedded in artistic and intuitive processes. The goal is to postulate new ideas, seeking innovation.

This paper presents design research evolving over the past decade. Starting with the first Solar Decathlon Competition in 2002, and proceeding through three more competitions, knowledge from each project has been transferred to and transformed by successive teams, developing higher levels of complexity. The 2002 project was a ribald confederation of pristine parts—functioning with minimal integration of systems. The 2005 house was reconsidered as a systemic whole. LumenHAUS, which won the 2010 Solar Decathlon Europe Competition in Madrid, Spain, furthers the integration of technology and architecture with the aid of digital processing and fabrication. The initial theme of the art of integration has been realized through a process of design that produces works comprising a simultaneous sense of the sustainable and the beautiful.

The origin of the work is pragmatic—keeping the sun off the façade of a building and reducing heat transfer. Precedents include shutters and

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Figure 1: Net-zero energy dwellings; 2002, 05, 10

screens that have been in use for centuries. Though presently employed extensively in other countries, the shutter has been relegated to a decorative element on buildings in the United States. It is the thesis of this research that reconsideration of the shutter and screen, using digital technology in conjunction with industrialized processes, can optimize energy use, make buildings more efficient, and improve the quality of architectural space.

BACKGROUND

Computer Aided Design (CAD), Computer Numerical Controlled (CNC) machines, and Computer Aided Manufacturing (CAM) have been the province of the automotive and aerospace industries. Until recently, design fields have peered with envy at the precision of the structure/function relation that yields innovative performance. This opportunity is now entering the consciousness of architects and designers, changing the conception and operation of normative practice. Speculation on the possibilities of digital tools in design and architecture are beginning to overcome the discrete specializations that typically govern use. Ideas from the areas of computer science and product development stimulate new territories of opportunity for the practice of architecture. The long-term goal is to make buildings more efficient, sustainable, and livable.

A net-zero energy, solar house comprises the larger context of the LumenHAUS project. (2) The concept of *Responsive Architecture* brought forth the need for an adaptive building skin. The focus of this paper is the *Eclipsis System*, an innovative fenestration of laser cut, stainless steel shutter screens. Their primary function is maximizing daylight while controlling solar gain. The screens adjust to climactic changes and user requirements through automated systems that optimize energy consumption while offering architecture of delight. Prototypes were developed through digital processes and tested empirically for performance. Water jet, die stamping, and laser cutting technologies were explored in relation to material characteristic and qualities, and alternatives were re-routed back through the digital process to find a more refined geometry while increasing performance.

ECLIPSIS SYSTEM—SHUTTER SCREEN

The initial design of the Eclipsis screen called for a double layer of laser cut panels, with offset openings to block summer sun but admit winter light. Grasshopper®, a scripting software program allowing for the development of variable criteria, was used to explore various patterns to be cut by laser or water jet. The original design was based on algorithms generated from structures of plant transformation and the geometric growth of crystals. This gave a vital image with corresponding content to the screen; however, fabrication issues and the difficulty of reconciling various criteria proved difficult. Though the design was dynamic and visually stimulating, its performance, particularly regarding sun shading and heat gain was unsatisfactory. In addition, the double wall demanded excessive material and fabrication time and proved problematic regarding weight, assembly, and maintenance. A great deal of time and effort was dedicated to the development of alternatives, but it was decided the process required an overhaul and a re-evaluation of criteria. A new path had to be charted.

MASHRABIYA—ARCHITECTURAL PRECEDENT

Mashrabiya is an element of traditional Arabic architecture used since the middle ages up to the mid-twentieth century. A screen separating inside and outside, the construction is usually turned-wood spools made of beech or mahogany. As the primary openings in dwellings, it allows a strategic interface between private and public space. (2) The root of the name derives from the word overlook or to observe. Simultaneously providing privacy and openness, it allows the women of the house to be shielded from view but have a connection to the street.

The wood screen gives shade and protection from the hot summer sun while allowing a cool breeze from the street to flow through. Gradations of openings increasing from bottom to top cause the air to move faster above one's head providing significant air movement without uncomfortable drafts. The system combines environmental response with cultural value meeting five primary criteria: blocks the summer sun; controls the passage of light; controls air flow providing natural ventilation; reduces air temperature; and maintains privacy and security. Thus, the delicate screen separates inside/outside, and private/public, while enhancing the quality of ventilation and light.

The social/cultural/technical implications of this centuries old building component inspired the development of an exterior wall system for a new type of dwelling. The imprint of the craftsman; the simple industrialized process of the lathe; the pragmatic response to climate; the unique spatial condition provided by modified sunlight; and the cultural value that can be read in the building component became conceptual criteria for the development of a new architectural product. Thus, the historical concept integrating technology and architecture finds expression in new materials and processes through digital technology.

The design search re-focused, emphasizing fabrication processes and material availability. A simple, repetitive circular pattern was chosen that could be easily fabricated and meet multiple performance criteria. By populating the screen with simple geometries of varying orientations, a more complex understanding of the parts to whole relationship of the shading pattern was established. Prototypes were developed and tested—at first small panels were produced and later full-scale mock-ups. An innovative aspect of the new approach is the circular geometry of laser-cut holes with tabs folded at calculated degrees (the idea came from the knock-outs of electrical junction boxes). The circular geometry allows for a repetitive element that can be manipulated according to multiple criteria. This system allows a four-fold role: to keep the summer sun off the façade, to offer degrees of privacy while providing views to the outside, to break sunlight into fractals that intensify and enrich the space, and to permit cross ventilation. The folded tabs have three variables—the diameter of the circular cut, the axial orientation of the tab, and the degree of tab rotation relative to the surface. These variables are articulated to block and bounce sunlight and to create views. For example, in the bedroom the tabs are only folded 10 to 30 degrees on a vertical axis favoring east orientation. This causes the rising sun to strike the backside of the tabs and bounce into the bedroom while

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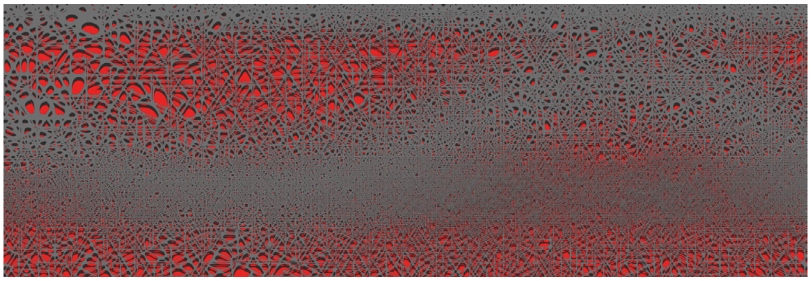


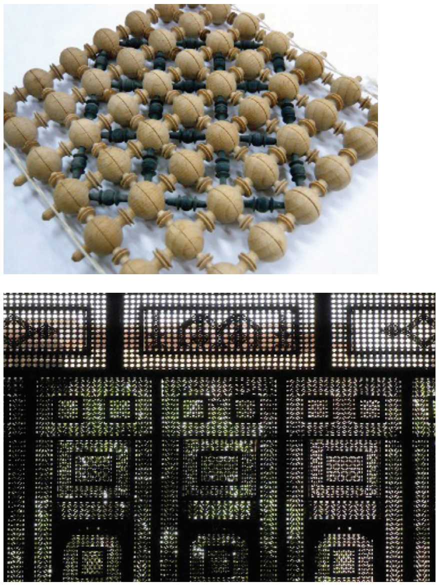
03


Figure 2: First visualization of screen pattern eventually rejected due to limitations of performance and fabrication

Figure 3: Turned, assembled elements of typical mashrabiyas and overall screen

blocking direct views into the space. In the dining room, strategic tabs are fully folded (90°) on a horizontal axis to create a direct view outside from dining height while blocking direct sunlight.

As a research platform the Eclipsis System's algorithmic logic was designed for mass customization. Shading, refracted light, privacy, and ventilation is woven through a complex definition designed within Grasshopper®, a graphic algorithm editor developed in conjunction with Rhinoceros®. Grasshopper®, along with Visual Basics programming-language allowed for the development of subtle complexity with extensive design versioning. Grasshopper® definition allowed for four user interfaces.

PROGRAMMATIC REQUIREMENTS

In the case of the open pavilion type floor plan (the shutter screen was designed for a specific situation, but it is scalable and can be used in many different sizes and combinations), the program was explored through an understanding of clear views and privacy. The relationship of open/closed was diagramed through the narrative of a typical morning routine. The occupant begins their day in the privacy of the bedroom, upon rising the disks open to allow views and light. The user then proceeds through the core of the house and finally sits at the table for breakfast where once again there is a clear view outside.

TIME

The effectiveness of the screen to shade while providing dynamic light is an integral aspect. The algorithm allows for refracted light to shift with the sun while also producing a smooth transition between lighting conditions.

GRADIENT

The algorithm's design allows for the customization of proportional relationship of the scale of opening and perpendicular rotation. In the case of this dwelling, the disk's maximum diameter of 3 inches represents a manageable manipulatable unit. However, in large-scale applications the scale of the screen could have much larger possibilities.

OVERRIDE

The complexity of the algorithm allows for a new understanding of imagery. Through the use of image processing, the *Eclipses System* has the capacity for versioning that integrates environmental reasoning with fashion identity. The algorithm provides the rationale for a physical gradient to be applied to any content (even image) the user chooses.

Prototypes were developed and tested—at first small panels were produced and later full-scale mock-ups. Prototyping along with industry collaborators provided a key understanding of feasibility and longevity studies. Industry fabricators were present throughout the entirety of design development and ultimately fabricated the final panel system. The use of prototyping identified four major fabrication considerations: assembly methods, fabrication tool, material gauge, and finish.

ASSEMBLY METHOD

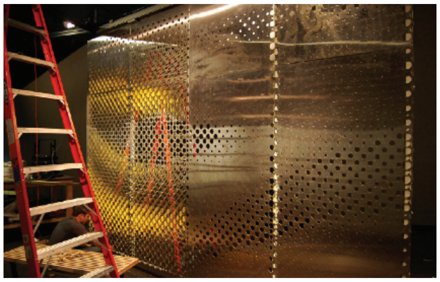
The assembly methodology established many of the fabrication considerations. Given the complex nature of the circular disc's rotations and the limitations of "off the shelf" CNC programming, it was determined to rotate the discs by hand. This presented many design criteria. First, a controlled set of nine rotation increments was established, ranging from 10 degrees to 90 degrees. This allowed for simple calibration "wedges" to be produced. Team members first bent the tabs out and then calibrated the angle of rotation based on the corresponding wedge. To understand the rotation of each disc, an easy-to-read map of rotation degrees and polarity was needed. First attempts at spreadsheet style mapping and scaled drawings proved problematic. Maintaining the correspondence between the map and actual screen was difficult. It was easy to get lost in the matrix of circles. A "paint by numbers" approach was adopted by realizing the laser could etch a number on each disc as it was cutting the metal. Each disc was etched with its corresponding angle on the exterior surface. Etching provided two streams of information: first the degree of rotation, and second the polarity or direction in which the disc rotated. Team members were informed to push in on the scribed number ensuring that the disc rotated about the polar axis properly.

The use of an etched numeric system provides a new level of legibility to the consumer. At first encounter, the screens appear only as a graphic representation. However, upon a closer, more detailed viewing of the screens, visitors are able to see the logic and controlled engineering of the screens. By understanding each disk as a predetermined rotation, the effectiveness of the craft is translated to the user.

FABRICATION TOOL

Three (CNC) methods of steel fabrication were explored. The first method, die cutting, was evaluated based on a fabricator's in house operations and extensive application of die-cut panel systems. Die cutting was ultimately dismissed due to the limited variations of circle patterning (six diameters) and inability to punch a concentric arc with a material tab. The second method, water jet cutting, provided infinite geometric variations, however the water jet produced a large kerf reducing the stability of the tab and resulted in a less visually compelling design along with a heavy "halo" effect in direct sunlight. Both die cutting and water jet cutting also proved to have limited capacity with regards to coding the individual tabs. Both systems could incorporate a system of symbols to denote angle, however each symbol would become a complete cut and detract from simplicity of the circle, ultimately appearing as unintentional markings. CNC laser cutting was


04a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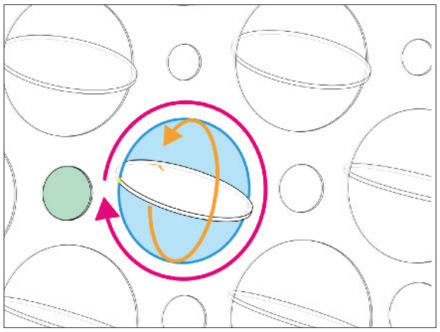
04c

Figure 4a, b: First full-scale prototype before and during disc rotation

Figure 4c: Diagram showing variables of size, axis, and degree of disc rotation

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Figure 5: Interior (above) and exterior (below) view of the shutter screen

chosen for the process's ability for tightly control cuts, unlimited geometric patterning, and laser etching capacity.

MATERIAL

As an exposed exterior-shading system, the Eclipses screen system naturally lends itself toward a corrosion-resistant material. It was determined that 16-gauge stainless steel sheet would provide the proper rigidity to prevent oil canning given the extensive perforations. The 16-gauge section also provided an ideal average thickness for resisting (moment) loads at the tab rotation points. Through multiple prototypes, it was determined that a viable tab thickness was required to sustain tab rotation beyond 60 degrees. This adjustment was allowed within the Grasshopper® definition by reducing the arc length for circles with a rotation angle greater than sixty degrees.

FINISH

The full-scale mock-up designed for an exhibition in a city gallery (see figure 4) provided immediate feedback on the exterior finish of the shading system. Although unfinished stainless steel provided the highest reflectivity, it also provided a large amount of glare. In order to reduce glare, a medium angel hair finish was abraded to the stainless steel.

The interior powder coated finish provides a new platform for efficiency and comfort. An understanding of the human factors of color perception allowed for increased energy efficiency. By using a cooler color, blue, user's perception of skin sensations shift, allowing for lowered cooling loads within the space. In addition, depending on the intensity and angle of the sun, and the position of the viewer, a dynamic quality of movement is achieved. From outside the color is revealed in staccato like moments as one walks by. From inside the color presents itself as an enclosing wall, partially transparent yet giving a sense of security and privacy.

AFTERMATH

All the discs on the house were folded by hand using a kit of inclined planes measuring 10 to 90 degrees at 10-degree increments. There is something reassuring in the fact that the last bit of the digital and industrialized processes was the touch of an individual's hand. However, the nostalgic gives way to the substantive. Thus, this paper ends with a reference to another paper that explores, and is titled, *Automating Eclipsis*[3]. The research explores the robotic folding of the *Eclipsis Screen* tabs:

> The part-to-whole relationship is reconciled by the aggregation of instantiated parametric geometry providing regulated, unlimited variation of tab size and rotation, and eliminating the need of any standardized fabrication method. A merger of Computer Aided Design and Industrial Robotic Manufacturing explores a prototypical comparison between manual and automated fabrication strategies. A highly differentiated computational geometry is integrated with advanced fabrication technologies, resulting in the production of a mass-produced, individualized, architectural building component. ◆

ENDNOTES

1. See http://www.saudiaramcoworld.com/issue/197404/the.magic.of.the.mashrabiyas.htm
2. The house has been exhibited at the National Building Museum and on the Mall in Washington DC; on Times Square in New York; Millennium Park, Chicago; in Madrid, Spain; and at the Farnsworth House in Plano, Illinois.
3. King, N and J. Grinham,"Automating Eclipsis: Automated Robotic Fabrication of Custom Optimized Metal Façade Systems", *Proceedings of the 2012 Robotic Fabrication in Architecture, Art, and Design Conference* (RobARCH 2012), Vienna, (Pending Publication 2012).