Crafting Eclipsis: Integrating Computational Design and Automation Through Programmed Craft-Based Fabrication in the Developing World

Digital design and fabrication are today deeply integrated into architectural discourse, where they have enabled new modes of practice and informed design pedagogy on a global scale.

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Whether driven by a desire for performance optimization, individualized customization, or formal freedom, designers have adopted these tools to expand the boundaries of what is possible in the built environment. Through workflow optimization and automation, designers are increasingly able to move seamlessly between the digital design environment, performance optimization, and simulation, to physical realization by leveraging advanced tooling strategies, such as collaborative industrial robotic work cells (Becthold 2010). These efforts are often employed only during the highest value projects or research projects in the developed world, where they lead to new territories in design exploration and enhanced building performance. In the developing world, however, the opportunity for computational design and fabrication to improve the built environment and participate in the development of requisite social capacity is not fully realized.

CONTEXT

In 2010, over 250,000 people in Haiti were killed in an earthquake that leveled buildings and devastated infrastructure. Three years later, the capital, Port-au-Prince, remained vulnerable to disease: in particularly, a recent Cholera outbreak that resulted in over 470,000 new cases in the first year. (CDC 2011) Buildings in the developing world are largely designed in isolation from the communities they serve. Often, local construction processes and materials are ignored and replaced by building systems with little cultural or economic relevance, perpetuating a systematic reliance on aid. In some cases the buildings that are designed to heal actually increase the spread of disease: poor building performance and infrastructure commonly results in the illegal dumping of waste content in local water ways, behavior which perpetuates the Cholera outbreak. Within this context, where the demand for increased building performance is great, the design community serving these regions has largely ignored the potential of advanced digital design technologies.

In response to the pending Cholera epidemic, permanent infrastructure has been developed by the MASS Design Group in partnership with Les Centres GHESKIO—a leader in Haitian-led cholera response, in the form of a Cholera Treatment Center (CTC) in Port-au-Prince, Haiti. The design of the CTC establishes a dignified, patient-centered treatment facility and localized sanitation system that will purify more than 250,000 gallons of sewage per year to ensure that water released from the facility does not contribute to the spread of disease.

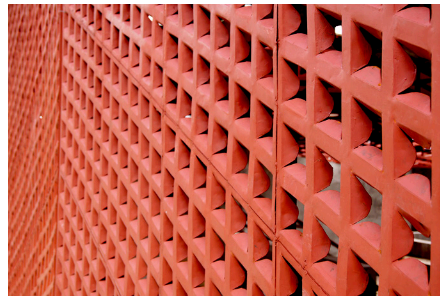
PROJECT DESCRIPTION

Based on a foundation of project-based research into healthcare building typology in the developing world, conducted by this paper's authors, the CTC building was designed to ensure four key components specific to the treatment of cholera: 1) easily cleanable surfaces; 2) ample airflow; 3) access to light; and 4) water treatment. The treatment facility itself is built in a partially-prefabricated pavilion-like structure, assembled on site. The pavilion is composed of a modular, broken-gable roof system, designed for enhanced day lighting and rainwater collection. This simple structure is wrapped in a strategically customized façade system that was developed in collaboration with a group of Haitian metal artisans and has been optimized for increased ventilation, decreased heat gain, privacy, ease of cleaning, and day lighting considerations based on specific programmatic organization. The shade screen consists of 300 self-similar steel panels containing over 32,000 individually customizable folded tabs: the detailed analysis and description of this façade design is the focus of this paper.

INTEGRATED ENVIRONMENTAL DESIGN-TO-ROBOTIC FABRICATION WORKFLOW

Based on programmatic demands and the need for individualized performance-based customization, the initial façade proposal incorporated the Automated Eclipsis Façade systems developed by the authors in collaboration with the Virginia Tech School of Architecture + Design, Center for Design Research and the Harvard Graduate School of Design, Design Robotics Group. (King, 2012) In this system, an integrated workflow enables the incorporation of environmental and programmatic parameters into a laser-cut, robotically manipulated, metal shade screen. The Eclipsis System utilizes a simple, repetitive, parameterized circular pattern to meet multiple performance criteria. The circular geometry of laser-cut holes enables multi-variable rotated tabs that can be articulated to block and reflect sunlight while creating controlled views and prescribed spatial conditions. (Grinham 2011)

In the developed world, the Eclipsis façade system presents potentially viable opportunity for building application, as seen in the Virginia Tech Lumenhaus, developed by the Center for Design Research. (Virginia Tech 2009). Unique conditions associated with construction in Port-au-Prince led the design team to modify the façade workflow to incorporate local expertise and local craftspeople. Based on subcontractor proposals, cost models showed that to remotely



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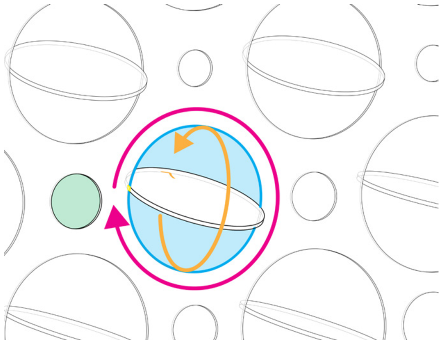
Figures 1 and 2: Virginia Tech, School of Architecture's Lumenhaus showing the first iteration of the Eclipsis Façade system. Credit: Robert Dunay, Virginia Tech.

Figure 3: Photo Montage comparing the robotic fabrication of the Eclipsis system (left) and the manual fabrication of the parallel CTC façade (right).



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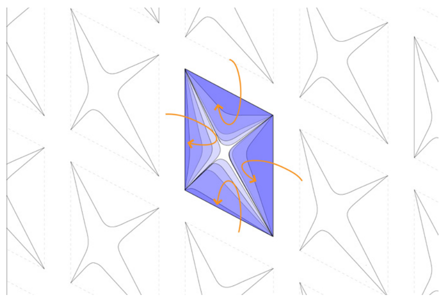

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production the façade system and ship it into Haiti would be both pragmatically and economically infeasible. Furthermore, the import of pre-manufactured building components is antithetical to the larger goals of MASS Design Group and Les Centres GHESKIO's partnership, which sought to leverage the construction of the CTC to build local construction capacity. Therefore, the design team proposed to manufacture the screen locally, while continuing to address increased building performance through computational means.

ADAPTED WORKFLOW FOR CRAFT-BASED REDESIGN

Previously established automated workflow algorithms developed for the Eclipsis screen system within Rhino 3D's Grasshopper® graphic algorithm editor and custom Visual Basic (VB) were adapted for the design of the manually-fabricated CTC screens. The initial definition established three design parameters, porosity (controlled through the diameter of the circular cut); shading (controlled by the degree of tab rotation perpendicular to the surface); and reflected light in response to solar orientation-controlled by the planar orientation of the tab to the surface. (Grinham 2011) In the case of the CTC, façade design parameters were driven by porosity in direct relation to programmatic requirements relative to allowable glare and privacy; see Figure 4 and 5.

To simplify communication of the fabrication instructions to the team in the field, the design of the CTC aperture required a paradigmatic shift away from design through continuous differentiation of discritized parts. In order to provide a facade system that could be cut, folded, and erected by the local workers, the team designed repeating, self-similar, trapezoid-like apertures with incrementally-folded triangular tabs. The simplicity of the system facilitated large-scale, craft-based production of the screen panel by local craftsman. It simulateneously allowed customization of unique parts relative to performance criteria through a controlled operational system, which consisted of five variables and a coded graphic communication standard.

The whole of the shade screens was envisioned as a continuous ribbon that was dynamically pushed, pulled, and tucked to allow for physical passage and spatial-programmatic differentiation. The figural use of a continuous ribbon provided a

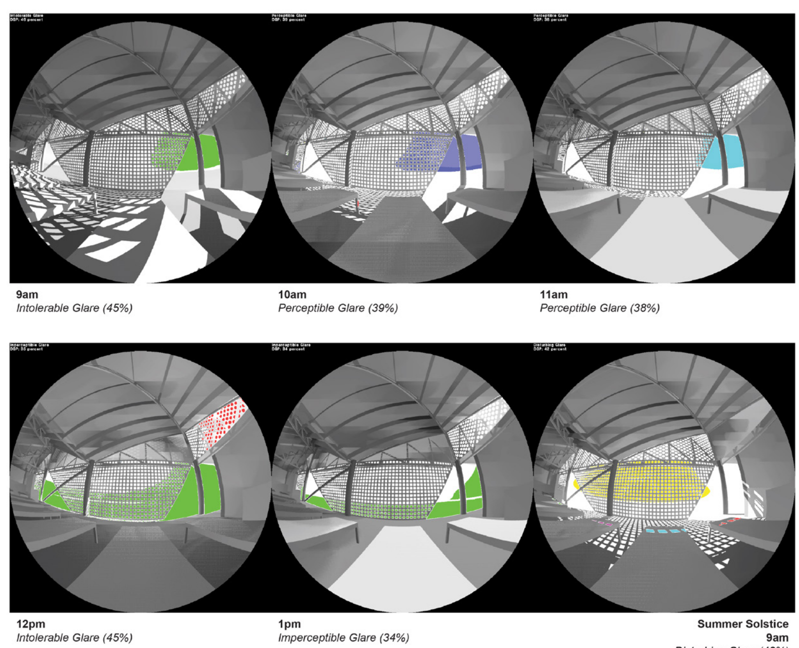

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Figure 4: Diagram outlining the parameters of the Eclipsis system in comparison to the neighboring CTC folded tab strategy.

Image 5: Diagram outlining the parameters of the CTC system in comparison to the neighboring Eclipsis folded tab strategy.

Figure 6: Daylight Glare Probability analysis for winter and summer solstice completed using the DIVA-for-Rhino software, courtesy of Kera Lagios of LAM Partners.

parallel column and beam grid that ensured uniform panelization with a minimal number of unique components. The resulting trapezoid-like panel was then subdivided to produce a uniform array of apertures. The size of each subdivision was based on three parameters: first, the feasibility of manual fabrication, considering that the increased number of apertures required increased time; second, tool feasibility, as all panels needed to be cut with a flat steel chisel and hammer, reducing the resolution of cuts in comparison to the laser; and third, the total structural stability of each aperture, considering that in this case a 30mm web needed to be placed between each aperture to ensure stability and to prevent 'oil canning', or surface deformation within each panel as it was being manually cut. With these considerations, a series of uniform cuts were prescribed whereby local craftsmen could locate and cut each aperture using familiar metal working tools and techniques. Each aperture consists of four tabs that are created by two intersecting cuts.

DEFINING PERFORMANCE PARAMETERS

Adequate day lighting, shown to improve patient outcomes, is a primary performance consideration of healthcare infrastructure. (Wakamura & Tokura, 2001; Walch et al.,2005) Early consultation with LAM Partners provided extensive day lighting analysis through the DIVA environmental simulation plug-in for RhinocerosTM and identified three primary lighting factors based on the use of a screen having 40 percent openness on the east and west facades. First, Daylight Autonomy (DA) (the percentage of the year any single interior point will receive adequate lighting), needed to be 500 lux in general patient areas, the minimum threshold for standard work spaces during 25 to 50 percent of the year. This could be achieved through 40 percent openness. Second, however, a 40 percent open screen during peak solar illuminance (9 am during the summer solstices) would make spaces immediately adjacent to the west screen over-lit (>2000 lux), while the remaining area would have a uniformly adequate lighting. Third, Daylight Glare Probability (GDP) indicated that during the summer and winter solstices, a 40 percent open screen would create a perceptible glare from 9am until 12pm, during which glare would be intolerable in some patient areas. As a result of these studies it was recommend by LAM Partners that the percentage of opening along both the east and west screens be reduced to insure consistent lighting throughout patient areas.

PROGRAM-BASED DIFFERENTIATION

Programmatic considerations were used to identify localized lighting and privacy needs to drive aperture differentiation. Both the east and west facades enclosed general recovery areas where patients are primarily reclined or horizontal in cots. For this reason, diagrams were established with the more closed areas at the base of the screen wall to provide privacy and reduced glare for resting patients and more open areas at the top of the screen to allow light to penetrate deeper into the space. These parameters were controlled within the Grasshopper definition and used to isolate specific fold dimensions.

The design team first programmed the screen wall using halftone gradient diagrams, which allowed for direct mapping of pixel data to screen opacity (see Figure 7). Here, mapping allowed for complete control of the total average percentage of opening on each façade. Based on the daylighting analysis above, the each apertures rotation was remapped to ensure that the average total openness percentage remained 30 percent. The final aperture rotation was remapped to a 15 degree increment, resulting in a 15 to 75 domain of rotation, ensuring glare reduction, while maintaining adequate total illumination and program-driven privacy.

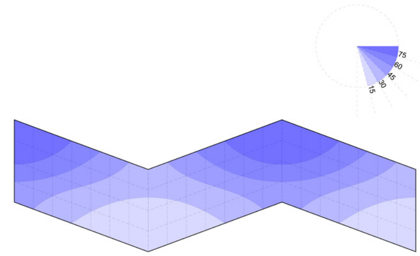

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Figure 7: Gradient diagram used to drive the façade optimization with corresponding color-coded angle definitions. Angle variation considered at 15 degree increments from 15-75 degrees.

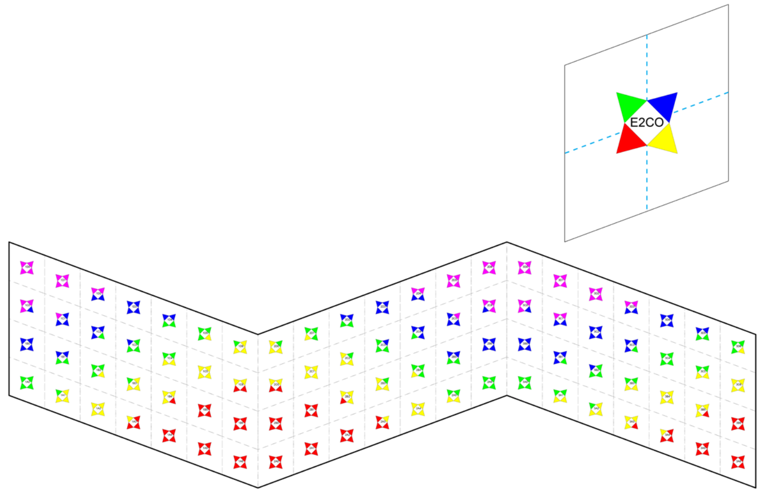

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Figure 8: Construction diagram, the final output of the digital script, enables easy field translation of folding parameters and installation positioning.

Figure 9: Hand labelling of panels based on printed diagrams.

DIGITAL WORKFLOW OUTPUT

In order to provide universally legible folding instruction, a simple, alphanumeric and color codification system was produced and automated within the previously described Grasshopper definition, which supplied a diagram for each panel that could be printed by the local construction team and tagged on each panel during production. The coded diagram included a color code for each quadrants folding angle, expressed through a triangle pointing at the specific quadrant and an alphanumeric code identifying the location of the panel on screen array (see Figure 8 and 9).

TOOLING

Working in collaboration with local metal craftspeople, the design team developed a series of fixtures to provide a high degree of repeatability to the fabrication process. Cutting procedures were well established and each craftsperson used their own unique technique to create the intersecting cuts. Five steel jigs were created to receive the incrementally folded tabs (see Figure 10.) To insure global uniformity, a wooden support structure was devised to register each steel fixture while supporting each individual panel during fabrication.

EXECUTION

First, the uniform cut pattern was transferred to precut-steel panels using a printed template and chalk. Metal workers used their own unique technique

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to cut each aperture and score each tab. While slight variation in this process occurred the commonality of tools (chisels and hammers) resulted in a globally uniform result. At this stage in fabrication each panel remains identical. Once cut the panel was supported on the previously described fixture, workers, following the printed color-coded diagram, used a series of steel jigs and hammers to incrementally fold each aperture resulting in specific individualized façade components. Individualization did increase organizational complication on site, but though strategic organization based on the coded digital output each panel was coded, transported, and welded in the correct position on-site.

CONCLUSION

In developed economies, the integration of digital design-to-robotic fabrication workflows provides unprecedented opportunities to increase building performance and expand design potential. In these scenarios, increased labor costs often support the demand for automation and, even through digital mechanisms, highly individualized building components are often not feasible. The same computational strategies are potentially viable in the developing economies where the demand for high performance buildings, and specifically high-performance healthcare infrastructure is great. By approaching computational design through the lens of craft-based fabrication, an opportunity is presented to both increase building performance and safety while also investing in sustainable local capacity by embracing locally available skills and materials. The façade of the GHESKIO Cholera Treatment Center (CTC) (under construction) in Port-au Prince, Haiti represents the successful implementation of an integrated digital design-to-craft-based fabrication workflow and will serve as a framework for further development of the opportunities offered by computational design in the developing world.

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Figure 10: Physical tooling including one of 5 incremental bending fixtures and the global support mechanism.

Figure 11: Manual cutting of repetitive pattern with Chisel and Hammer.

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Figure 12: Installation of finished panels on site.

Figure 13: Current state of progress, east façade installed, interior view.

Figure 14: Current state of progress, east façade installed, exterior view.

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