ADAPTIVE SKIN: PERFORMANCE DRIVEN DESIGN AND FABRICATION

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University of Cincinnati[1], Southern Illinois University Carbondale[2], University Of North Carolina at Greensboro[3]

1. Introduction of Performance driven design

Recently, architects have realized the potential of performance driven design (PDD), where the architects' prior experience is replaced by simulated evaluation and data-driven feedback loops. Oxman described how performance driven design is "informed by internal evaluative and simulation processes." (Oxman, 2009) Some of the emerging aspects in the practice of architecture involve utilizing PDD in the early design process to seek the optimized form. PDD is usually intertwined with simulation and rule-based tools in order to generate complex systems and geometric relationships that respond to environmental constraints. It becomes a generative process, and as Hesselgren argues that PDD is "not about designing a building. It's about designing the *system* that designs a building" (Stocking 2011). PDD has the capacity to optimize a single design solution based on environmental, programmatic, structural data, and is useful to respond the predefined social and cultural parameters.

This paper investigates a collaborative teaching and research agenda between the University of Cincinnati, Southern Illinois University, and the University of North Carolina at Greensboro. The primary investigation seeks PDD through parametric design and rapid prototyping. By examining various analog and digital approaches, including theoretical investigations and proprietary software tools, the authors have investigated the process of adapting geometric forms to input and external parameters.

2. Teaching Methods & Collaboration

With several design courses taught in 2011, the authors created a series of "adaptive skin" projects which studied the parametric relationship between human and geometric surfaces. The shared curriculum and reading materials allowed the authors to discuss parametric thinking and data processing as essential elements for its application of various PDD methods. At the University of Cincinnati, students investigated a 400,000sf reused building in Chicago. The challenge was how an adaptive building skin was applicable to such scale and external conditions such as solar, water and wind. At the University of North Carolina at Greensboro, the concept of an adaptive skin was taught as a means to generate a garment which was controlled by the humans' systems (the most sustainable and complex system).At Southern Illinois University, the measurement of performance were processed by transforming weather data , sound and user movement into real time information. Students, at all universities, were introduced to non-conventional design methodologies including genetic morphing, scripting, and simulation as means to investigate PDD.

2.1. Technical optimization vs. Human optimization

From the beginning, the authors decided the PDD approach should focus on not only structural and environmental factors, but also social and cultural values. The social or cultural parameters are associated with human optimization process, while the structural and environmental parameters associated with technical/computer optimization process. (Figure 1)

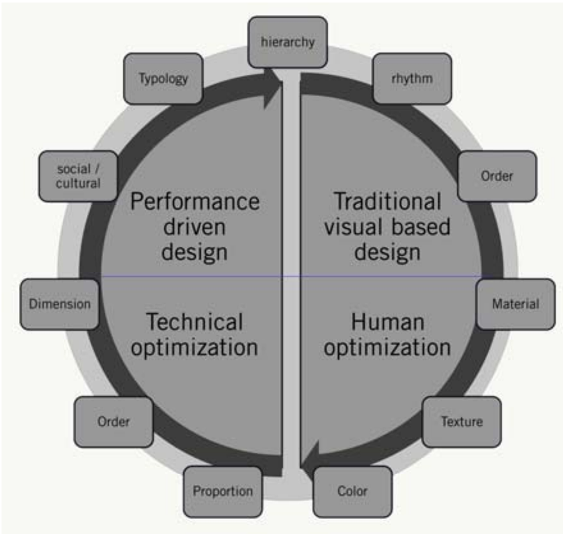
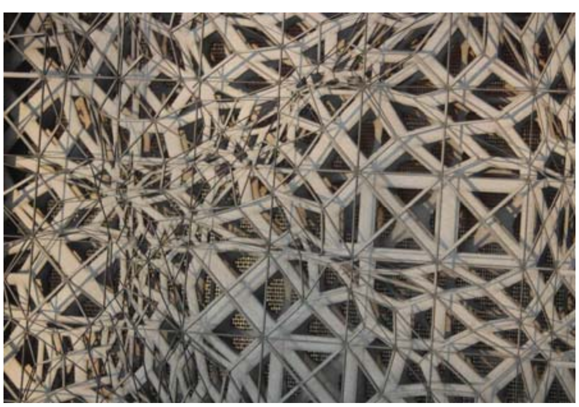


Figure 1: The organization of Technical and Human optimization.

Pattern making and origami folding were introduced as exercises and discussed within the matrix of environmental, structural, social and cultural elements. For instance, a student's project applied the technical optimization of complex systems in responding to solar radiation data, which drove an armature's open/close operations. Meanwhile, the human optimization looked to create a unique cultural value in terms of patterning or solid/void relationships that extend beyond the technique expectations. Here, both visual and utilitarian parameters were driving the optimization of the armature and the entire paneling system (Figure 2).



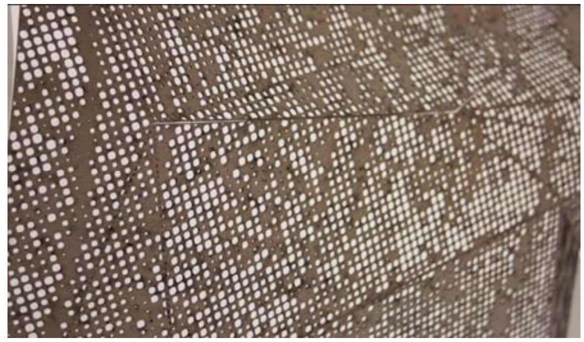


Figure 2: Students used performance analysis to control the adaptive system to inform design. They investigated digital design and prototyping processes that PDD permitted in order to formulate a generative system. Students produced a series of iterations that were filtered and selected based on performance criteria as well as the feasibility of fabrication and materialization processes. By Kevin Donovan, and Charles Wiederhold , University of Cincinnati.

2.2 Rapid prototyping

As a simplified approximation of a complex system, both physical and virtual prototyping were used to study the relationships of the parts to the whole. The authors believe the PDD developed through prototyping methods should be the foundation for decision-making by architects. The authors also realize the necessity of introducing parameters related with materialization and expanding the PDD into the fabrication of the designs. This integrated approach investigates how the form can be optimized based on the feasibility of fabrication and materialization processes of laser cutting, CNC milling, and 3D printing. The parameters such as tolerance, strength, and elasticity are used to optimize the design solution to adapt to these constraints.

3. Projects

3.1 RE:SKIN

The Re:Skin Studio was an collaboration with Perkins + Will Architects [i] which explored the adaptive building skin of a ten story cold storage building in Chicago. Using PDD methods, the students at the University of Cincinnati developed several schemes to reflect the relationship between the building skin and the cultural and environmental parameters.

Designed by student Suncica Milosevic, "Frozen Reminiscence" was one of the eleven student projects from this studio. (Figure 3) The first design step was a paneling system whose modules were geometric ice crystals. It was inspired by the snow flake shape, which has a relationship to this cold storage building. The density of pattern was parametrically driven by the solar access simulation in Ecotect. The density and complexity of pattern would increase where shading was more necessary.

The second step took the first approach and added the complexity. In instead of utilizing a single plane screen, there would be three layers of screens, each with its own level of intricacy and density of pattern. Autodesk Maya program was used to develop the initial hexagonal grid, which was later manipulated through the program's tessellation tools. Thus when same size modules of varying patterns overlapped, a new increasingly complex and dense pattern resulted.

The third step was developed through Maya program driver key and surface paneling technology. A single plane screen whose pattern would display a gradient of apertures was designed. This was achieved by designing a single, snowflake like geometric pattern whose offset value was set as a driving parameter. An undulated surface representative of the solar access map was populated with this pattern.

Finally, the student designed a structural frame for a set of three layers of geometric screens. Three screens were estimated with 20%, 40%, and 60% opacities. The solar exposure of each of the four facades was labeled according to these 20, 40 and 60% shading needs so that the placement of the three main screens could be most accurately determined. The solar data was further manipulated to achieve a higher level of variation and interest while still maintaining these three general zones. Thus the screens were overlapped and populated upon these facades in a more intricate manner where two additional pattern screens were used to achieve this variation.

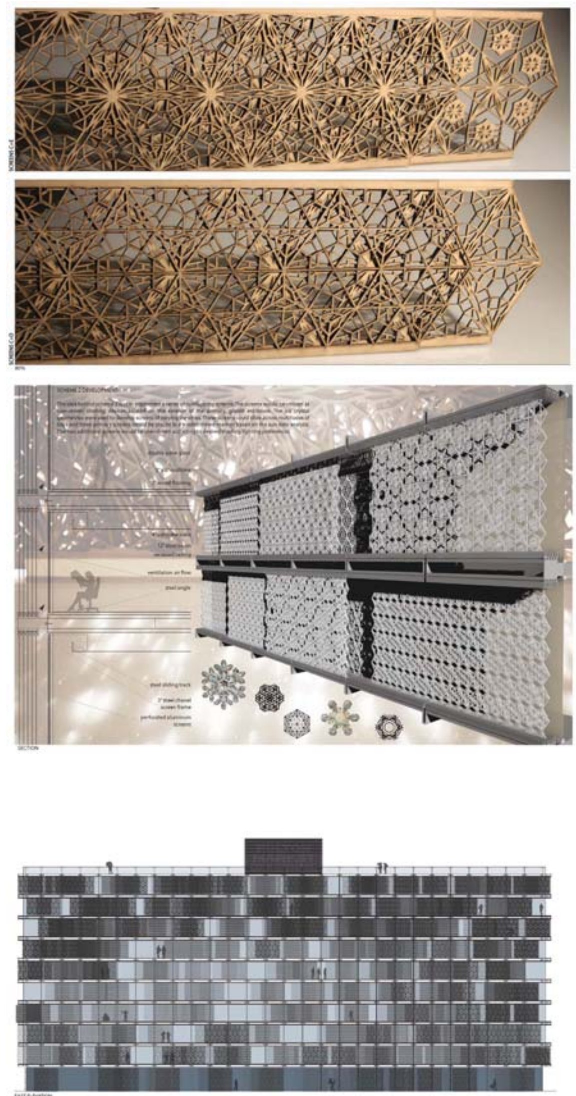


Figure 3: *Frozen Reminiscence* project. By Suncica Milosevic, University of Cincinnati.

3.2 Anthropometric Runway

This studio course taught in UNCG introduced students to the understanding of the body size, scale, and proportion. The garment project titled "Voxel" was designed by Chrisitine Lumans, second year interior architecture student at

UNCG (figure 4). In her project, a three-dimensional grid system was devised to measure the bodies' movements. Various yoga positions were performed within the grid system to demonstrate and measure the changed shape within the controlled space. After studying the movement from one position to the next, a two-dimensional solid/void block study was done in order to understand how much space was occupied in each position.

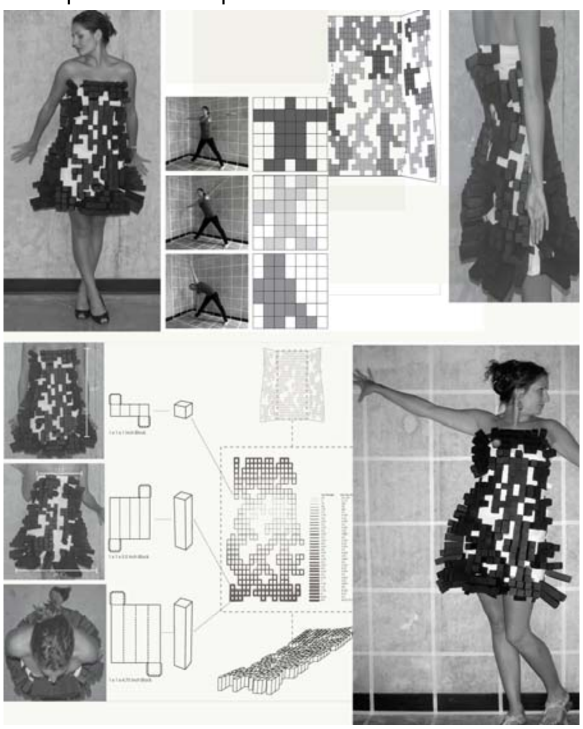


Figure 4: Voxel project by Chiristine Lumans, University of North Carolina at Greensboro

This study resulted in three shapes which were then duplicated and strategically placed to coalesce into a pattern for the garment. The pattern was placed on a form-fitting white strapless dress made especially to the measurements of a particular body. To emphasize the scale, proportion, and three-dimensionality of the body, blocks were placed on the garment in the same pattern as the solid-void block figures.

The one by one inch blocks on the garment varied in height based on their proximity to the navel. The navel was chosen as the center point because the yoga positions performed for this study emphasized the core of the body and centered about the navel. As such, the greater the distance away from the navel the boxes were located, the taller the boxes; thus emphasizing the shape and curvature of the body.

3.3 Real time data processing

Using the concentric principles defined in the beginning of the research process, the inherent organization of a module was explored within predefined domains by the students in the Southern Illinois University Carbondale. Levels of porosity and density were then influenced by the input of weather data such as temperature, humidity, along with light, sound and user movement that were processed to inform the designers about an expected behavior. In one instance the response informed the reasoning behind the static form, on the other instance and on a more localized scale the surface was composed of actuated cells that were programmed to respond in a network structure to a pre definied condition such as ventillation, or shading. The workflow process began to output a variation of contextual responses that measured the outcome. In return this process became iterative and was able produce a series of outcome that were performance driven. (Figure 5)

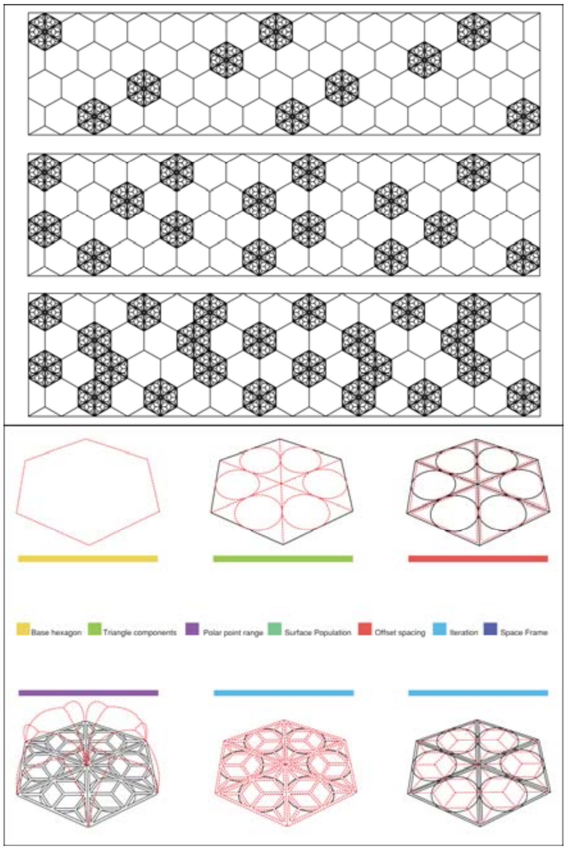


Figure 5: Geometrical manipulation at the micro (local) and macro (network) scale. (Research assistant: Zach Potts) Southern Illinois University Carbondale

In addition to surface porosity/density exploration, vertical space frames also played an important part of research. Structural possibilities of polyhedral and the interrelated angles that define them were no longer subject to static existence. Allowing the input of data to extrude and expand, new variations that encompass many of the traditional characteristics were revealed. Vertex, edge and surface remained to be the defining features of the geometry.

Through investigation of climate data it was shown that the structure (both skeleton and skin) in a specific site were exposed to the sun in such a way that change in season had little to no alleviation of the stress from radiation (fig.6). This potentially yielded environments within the tower that were only habitable during certain portions of the year. A solution that could respond over time to the levels of radiation became the objective. The second phase of the research addressed how a localized application of a responsive system could enhance the performance of the building in such extreme climate. (Figure 6)

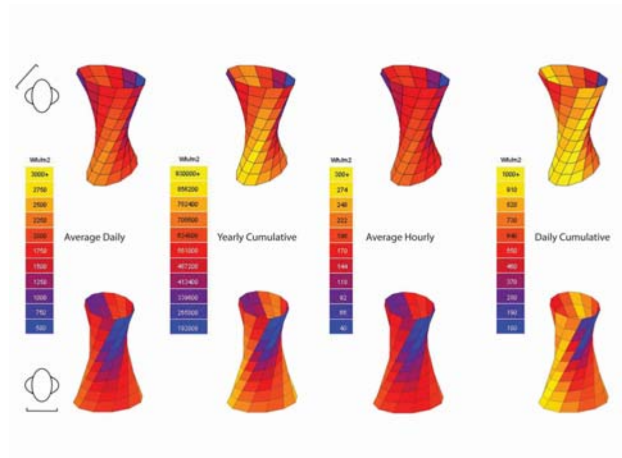


Figure 6: Ecotect was used to address radiation to better understand and refine the design process and criteria's selection. (Research assistant: Zach Potts)

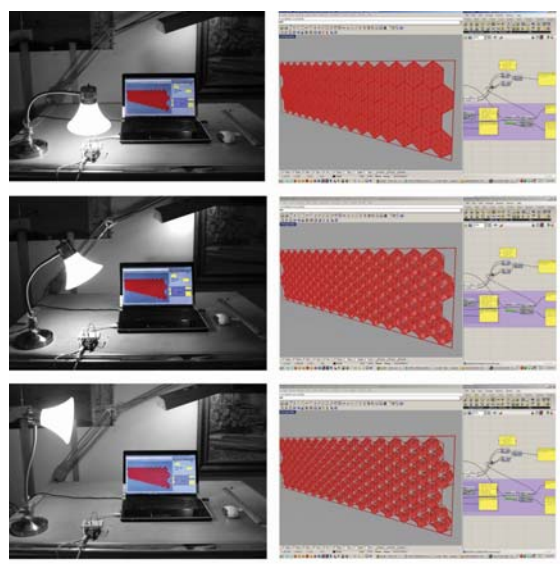


Figure 7: light studies and response time of the parametric model. (Research assistant: Zach Potts)

The students utilized a series of Rhino / Grasshopper compatible software to generate site specific data for evaluation. The same process was used to develop and design the unit/module in phase one of the research. In parallel, arduino and firefly were used to test light as a real time input in order to actualize a working physical model. (Figure 7) The investigation concentrated on how a localized system responds to light change. The real time lighting data was collected and sampled in firefly and filtered based on a predefined condition. This constant data input enabled the optimization process to occur. The affecting criteria, such as number of user, time, location, sound level, and weather conditions outside, informed the objects behavior. (Fig.8)

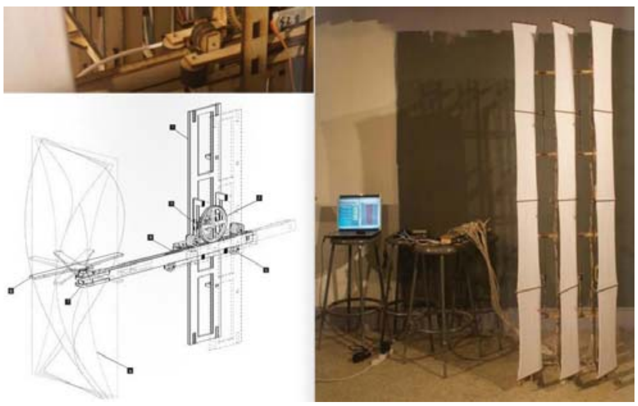


Figure 8: Privacy Wall; a responsive system to user and external data (Research Assistants: Steven Kocher, William Sedig, Brandon Veith. Southern Illinois University Carbondale

4. Conclusion

These experiments explored the formation process that both technological and human optimization permits in order to sustain a PDD system. By analyzing several design and prototyping procedures taught in the three different universities, the authors are creating a new relationship among form, meaning, and performance. Simultaneously, the authors are promoting a new teaching methodology that requires students to think about how design is interacting with the built environment. This research intends to show an inventive approach to merge new ways of thinking, which are performance driven in terms of functionality, as well as driven by social and behavioral performance. Through this investigation the authors gained the experience of how to teach students to use physical and virtual prototyping to study the parameters and their relationships to the form and its performance. This ongoing investigation will continue to develop and increase our understanding of parametric design as it relates to performative capabilities and the forces that affect them both.

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[i] The architects in Perkins + Will involve in the Re: Skin studios are Dr. Ajla Aksamija, Todd Snapp, Michael Hodge.