NATURE AS A COMPREHENSIVE MODEL:
A BIOMIMETIC INSTALLATION

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Abstract. The following group installation was part of a seminar on biomimetics at the University of Arizona, USA. The design began with research into various natural systems, namely cell growth and morphogenesis and digital tools. In nature cells contain preprogrammed responses based on intrinsic properties which allow for differentiation and adaptation to external forces. This logic of cell morphology was developed into the installation design. Form specificity and topological variation was developed through the manipulation of a material system, bending and loading identical components to adapt to external forces, such as the sun, while simultaneously navigating the site, providing structure and ultimately architectural space.

Keywords. Biomimetics; pedagogy; simulation; design/build.

1. Introduction

Anthony Vidler in his essay ‘Architecture’s Expanded Field’ of 2008 wrote that biological analogies were one of the four dominant emerging principles of contemporary design. He believed that these new expanded boundaries for the profession could help to create a truly ecological aesthetic for the first time.¹ Historically, he states that the biological influence in design increased with the dissemination of Charles Darwin’s theories in the late nineteenth century and with research into DNA and cybernetics in the mid twentieth century. In this paper the authors have chosen to equate biological analogies with the term biomimetics. The Centre for Biomimetics at the University of Reading, UK defines biomimetics as "the abstraction of good design from nature."² It is not about mimicry or the simple observation of nature, but more about an investigation into its systems and processes and how these can help us move forward with our societal and environmental concerns.
Recent architectural discourse on the topic of biomimetics has been led by the publications of the Architectural Association’s Emerging Technologies and Design Program [AA Emtech] in London, UK, originally founded by Michael Weinstock and with important contributions from Michael Hensel and Achim Menges. Their writings have also reintroduced a generation to the work of Reyner Banham and Frei Otto, to name a few, emphasizing the need for form-finding verses form making, questioning the trajectory of the developed world’s commitment to designing "massively structured methods of environmental management." (Banham, 1969) The following project, Cellular Noise, attempts to work from the philosophy set out by Reyner Banham and Frei Otto, and currently being developed with the help of computational processes by the AA Emtech group and its followers.

The design and fabrication of the installation was part of a 3-credit seminar class on biomimetics at the University of Arizona which took place in the spring semester of 2013. Initially students researched various concepts, digital processes (Figure 1) and precedents related to biomimetics, and then they worked in groups to propose design/build installation proposals for the remainder of the semester.

Design/build projects encourage a level of reality that is beyond a virtual or representational resolution emphasizing a whole expanded field of pedagogical issues, from the relationship of the digital to the real to the resolution of craft. In this specific class the goal of the installation was to question the typical trajectory that architecture follows and to see if studying the natural world (the ultimate in performative design) could lead to new forms and systems that would be more sustainable (socially, environmentally and economically).

2. Biology as a precedent

Any approach to architectural design that aspires to engage with biological precedents must, by nature, originate from a process of continuous integra-
tion, of synthesis. "Biological organisms have evolved multiple variations of form that should not be thought of as separate from their structure and materials. Such a distinction is artificial, in view of the complex hierarchies within natural structures and the emergent properties of assemblies. Form, structure and material act upon each other, and this behavior of all three cannot be predicted by analysis of any one of them separately. " (Kotnik and Weinstock, 2012) As in the description of natural form that evolves from processes of morphogenesis, architectural design too, can be thought of as originating from a process of negotiating between the potential inherent in a material system and a complex field of external parameters or forces. "Just as the association of material systems with gravitational fields depends on their mass, so the association of systems with morphogenetic fields depends on their form. Hence a morphogenetic germ becomes surrounded by a particular morphogenetic field because of its characteristic form." (Sheldrake, 2009)

The physical evolution of form is generated through the simultaneous morphology of complexification (continual reintroduction of a higher order morphic unit) and specification (continual adaptation of individual units to evolving localized conditions). This process of deriving overall form from the multiplication of units and their continual re-adaptation is precisely the kind of open network form generation model that has profound potential if deployed in architectural design, the effective replication of which begins to address a new territory of possible efficiency that is demonstrated in biological systems.

The ultimate design was based on research into cell growth and morphogenesis. The basic unit at play in Cellular Noise involved a material system embedded with an implicit potential in the form of its multiple performance. The design process itself operated as a complex ecology of prediction, composed of a series of physical and digital components, that, over time, analogous to a ‘morphogenetic field’ of evolving parameters, represented the collection of inflections and mutations that engendered a final form. Through this process, all forms of modeling and design evaluation, from simulation to prototyping were simply steps in the evolution of a design, not yet representations of a preconceived design. "What we are witnessing is a shift in the traditional relationship between reality and representation. We no longer progress from model to reality, but from model to model while acknowledging that both models are, in fact, real. As a result we may work in a very productive manner with reality experienced as a conglomeration of models ... Models have become co-producers of reality." (Eliasson, 2007) (Figure 2)
3. Digital and Analogue Process

The design process began with the establishment of a material system that was specific yet flexible enough to absorb permutations in performative criteria. The resolution of initial form was first understood through a series of physical and digital prototypes. Beginning with scale prototypes to establish material principles that would generate this form, digital physics simulations were then incorporated to expound the geometric scope and performative properties. Full scale physical prototypes and digital simulations became a feedback loop between the digital and analogue; as knowledge of material properties informed the calibration of the digital model and the extrapolation to form and structure. This process was complex particularly with the less predictable elastic materials. Eventually a simple yet broadly variable form was reached, composed from a single loop of elastic material and a tensile fabric membrane, chosen precisely because the level of its simplicity was also the breadth of its potential. The geometry of the base unit is defined in topology as an Enneper Surface, taking the curvature of a hyperbolic paraboloid, formed by the pre-stressing of the material system. Prototypes included the testing of various materials in the elastic structural chord (polyvinyl chloride, polyethylene, polycarbonate, aluminium, steel, and fiberglass reinforced polymer) in combination with multiple composite fabric materials and stitch formations in the tensile membrane (Figure 3). The final material section was the combination of cross-linked polyethylene tubing (PEX) and a constraining synthetic fabric membrane, known as Power Mesh, leading to a balanced material composite, the tubing’s elastic material property, gave it a high range of deformation, while the stitch of the fabric gave it equal omnidirectional tensile properties. Throughout the dimensioning and material choice processes that made up each unit, it was understood that a preliminary layer of formal specification, in the form of the ‘tightness’ or ‘looseness’ of a particular unit, could occur within the material balance of each unit. Principally, the stress of the fabric when forced into tension applies an internal...
force too great for the ring to resolve through bending, causing it to deform through torsion (twisting) which results in its buckled form, "the folding of rings results from a continuous evolution of their torsion and curvature. The stored elastic strain energy can then be used for self-deployment." (Mouthuy et al, 2012)

This behaviour and the precise manipulation of this material balance was the impetus for defining overall performance, controlling the potential variation to the optimization performance, as the outer curve of the geometry shifts, its curvature and torsion are inversely proportional. This proportionality meant that the geometry could be broken down at four critical points (maximum torsion, and minimum curvature) dividing it into four arcs, each incidental to an individual plane, the intersection of which produced a tetrahedral bounding geometry (Figure 4).

This capacity and potential for the tuning of each unit to a specified form was modelled and simulated digitally in Kangaroo, a physics simulation plug-in created by Daniel Piker for McNeel’s algorithmic modeller for Rhino, Grasshopper. Initially slider tools were incorporated into the parametric,
digital model that could vary the membrane tightness relative to an outer circumference dimension. These initially varied for each simulated fabric type until the Power Mesh was selected. The Kangaroo simulations calibrated this elastic deformation and established the initial module’s form (Figure 5).

Figure 5. Stills from single module simulation

This calibration became a feed-back loop between the digital and physical models, with the outer ring circumference being finally set at nine feet, a size which was physically manageable by one person. After multiple simulations and physical prototypes the fabric diameter became 50% of the tube diameter. In reality the final diameter of the fabric membrane was ultimately larger as it was dependant on the wrapping/fastening mechanism of the fabric to the tubing of the ring. This detail was not simulated in the digital model, though. The Kangaroo model was designed to allow different properties relating to elasticity, stress and strain for the ring, which represented the outer tube, versus the membrane, which represented the fabric. This variation allowed the model to approximate the two different material behaviours (Figure 6).

Figure 6. Diagram showing different parameters in Kangaroo digital model
There were also multiple digital iterations of how the fabric should be subdivided in order to approximate equal tension. More uniform tessellations were ultimately selected over those which biased the geometric centre. After the initial module became more defined aggregations of modules were explored. This resulted initially in clusters of three modules, chosen for structural simplicity and strength. The final system of connections through which the clustering was achieved was a series of stitches that joined two units along partial lengths of each edge transferring loads through alternating unidirectional stresses. These joints between units were approximately a third of the circumference of the tube, which allowed the cluster to be open enough to receive another cluster. This behaviour and variation was again determined in part by simulations in Kangaroo, where connection lengths were varied from a quarter to a half of the circumference of individual units. Digital simulations showed this entire clustering process (Figure 7).

The digital analysis of incidental solar radiation levels modelled in Autodesk’s Ecotect and Geco, by uto for Grasshopper, relative to the simulated geometric permutations lead to further resolution of the clustering logic. Scale prototypes were studied in tandem to produce overall geometric ordering of multiple clusters as a structural variable, e.g. unit to unit connections as an additional layer of stress in the material balance, introducing asymmetrical formal variation into the matrix of possible deflections.

Finally the understanding of surface geometry to optimize lighting and visual effects became a key area of study. Testing and prototyping continued with various lighting systems, coloured fabric combinations and environmental measurement tools. These digital and analog prototypes enabled the testing of certain light and material effects, such as the reciprocity between material translucency and geometric layering in the dispersion and diffusion of light through the fabric membrane, and the testing of layering and color in the fabric membrane to achieve an ideal balance of natural light reflection and absorption.

The final form was complex in its variation and resultant performance, with a particular part to whole relationship: its final specification was a direct interdependence between structural versatility and topological complexity. Cells on the outside remained relatively normal in shape, providing lighting/shading, while cells closer to the centre of the overall cluster were more
distorted from their original shape, absorbing a higher range of stresses from all directions and transferring greater loads. The final performance of the piece as a structural system in fact depended on its inherent flexibility, withstanding strong winds and rainfall, as well as acting as an ideal shading device, provide light enclosure and shade whilst permitting air movement and ventilation (Figure 8).

Figure 8. Images of final installation from day to night showing varying lighting conditions

The final performance indeed resembles the complex emergent patterns of cell morphogenesis; each unit inherently falling into a specified order with an overall system in order to remain cohesive. The differentiation of units as well as the three dimensional geometric nature also led to the desired overall lighting and shading outcome as well as the dynamic moiré visual effect. The complex variation in form was ultimately resolved through the clustering logic, which synthesized all the physical parameters including structure, light permeability, solar deflection, and visual effects; "very complex behaviours can emerge from the action of simple operations, and, by extension, very complex forms can emerge from the action of comparatively simple machines." (Davies, 2005) The reality of which is that simple variability led to complex specificity, confirming the principle that an approach to design through a logic of synthesis and interdependency generates not only efficiency but elegance.

4. Findings

Much of the final project’s resolution and methodology imitated issues of real-life building scenarios. The project was fortunately completed on time and on budget (including prototyping), but the pressure of producing a final product did lead to some compromises along the way.

As a whole the process had a fairly successful outcome for a small, semester long undergraduate class for twelve students. Due to the short design time regrettably it was not possible to involve a structural engineer as planned, however the process of operating with several scales and methodologies of prototyping concurrently was indispensable to the final resolution. Even with the coordinated effort of physical and digital modelling and simu-
lation it was difficult to predict the full behavior of the modules in a larger composition. Given greater time and effort it would have been productive to develop a digital model that could simulate the forces of connecting modules more accurately. The more that can be simulated in advance, although often technically challenging, is obviously an asset to any project. Any media, process that can help predict a design/build (which is always more laborious than anticipated) is a positive environmentally too.

5. Conclusion

Biomimetics as a principle design driver was successful to varying degrees. The project began to integrate ideas of materiality, form and force in a lightweight approach to a 3-dimensional system of enclosure, shade and experience. "The lightweight construction principle is one of the most important foundations for the evolution of objects in living nature and in engineering." (Otto, 1998) The project adapted itself in its overall form and external context like the morphology of cells, but is that enough when compared to the dynamism of the natural world? Not to say that everything needs to be dynamic in a literal sense, but responding to environmental elements, like the sun, does imply some level of flexibility within the system. The project failed to reach this aspiration for an adaptable system of movement related to the sun’s path. It would also be optimal, on a next iteration, to have a more rigorous digital model with input from a structural engineer skilled in the analysis of non-linear systems.

During the process of the course there was much discussion on sustainability and the desire for the ecological aesthetic that Anthony Vidler had originally forecast. The project anticipated a change in thinking from a more typical heavy, linear structure to a lightweight, more fluid outcome. This enabled a fast, fairly straightforward fabrication and installation process. The materials were also very affordable; sustainably issues of economics and the environment were addressed, but what about the social aspects? The project was obviously a collaborative effort, but was creating a 3-dimensional enclosure enough in terms of having some social outreach? The intended outcome was to design an enclosure for the Beaux Art Ball, but it was also seen as an opportunity to engage (at least temporarily) with the community (Figure 9).
Endnotes

2. http://www.reading.ac.uk/biomimetics/about.htm

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