Bursting Margins [Involute Assemblies & Emergent Profiles]

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I showed my masterpiece to the grown-ups, and asked them whether the drawing frightened them. But they answered: Frighten? Why should anyone be frightened by a hat? My drawing was not a picture of a hat. It was a picture of a boa constrictor digesting an elephant. But since the grown-ups were not able to understand it, I made another drawing: I drew the inside of the boa constrictor, so that the grown-ups could see it clearly. They always need to have things explained…
–Antoine de Saint-Exupéry, The Little Prince, 1943.

Explorations on architectural envelopes have historically found their analogy in the anatomical or the biological body as models of both order and parthood. Cladding and structure have acquired in this way their conceptual status and alleged physiognomy through the analogy of skin and skeleton. The dialectic present in this binomial of skin and bones has instilled axiomatic assumptions of both spatial and material order: where the earlier maintains that one thing is simply inside the other, the latter is caught in the mutually exclusive role of the skin as either load-bearing and fully modulated with excessive engineering associations, or free from structural implications and subject to fetishized tectonic detailing or sculptural articulation.

This is not only a discussion about the functional (or even performative) role of the architectural envelope, but about the tense relationship existing between abstraction and materialism. While in the former, the architectural object is bound to remain ephemeral in order to favor representational purity, in the latter it accepts pure constructive determinism and dissipates its formal ambitions into a kit of multiple parts.

Speculating on an architectural object that assumes a more contested relationship with form and material, Bursting Margins adopts an alternate attitude towards enveloping. Bursting Margins argues for a more complex part-to-whole relationship. By virtue of perching robust modular frames within loose and tight flexible membranes, Bursting Margins pushes for changing material qualities supported by the introduction of live physics modeling software.

The approach not only forces the simultaneous consideration of rigid and soft materiality, but more importantly builds up a position for inchoate forms of material expression by exploring strong, yet transitory profiles—a

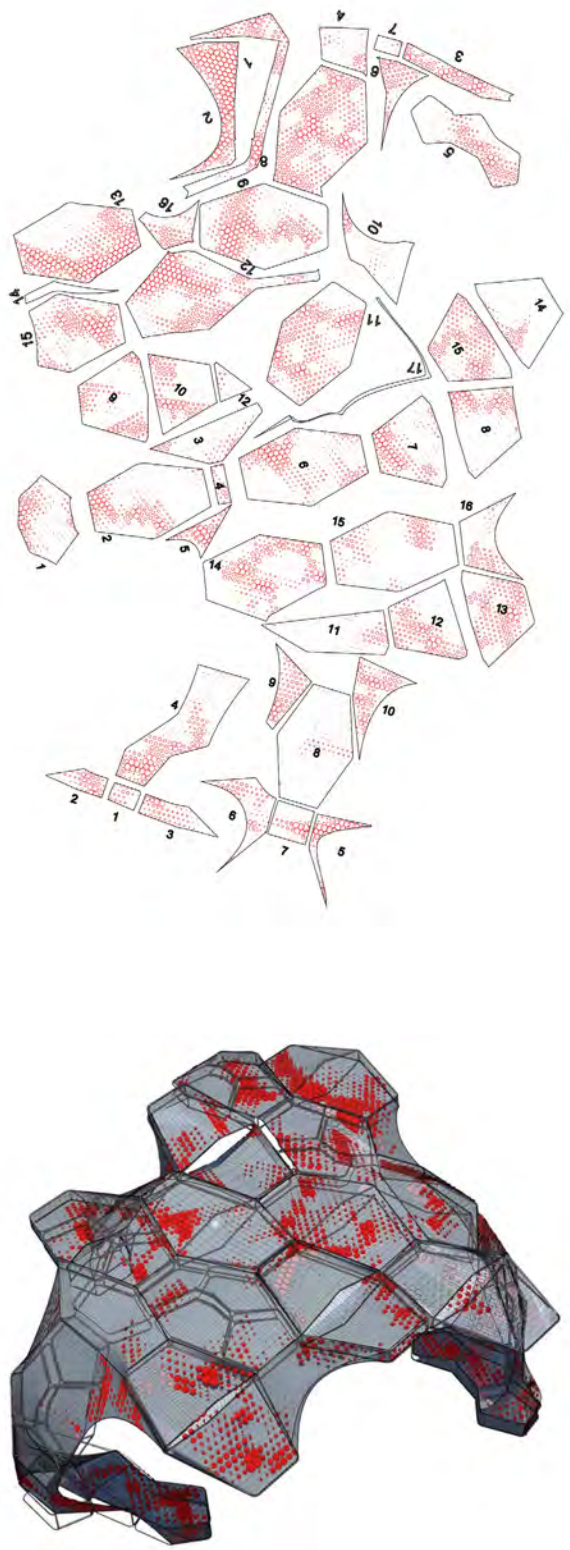


Figure 1: Birds-eye perspective of canopy structure and flat developed patches of membrane broken through seams

byproduct of shrink-wrapping otherwise hefty frames. Can a mutant typology for the envelope be born out of the juncture between the rigid and the elastic, so that profiles become at times unmistakably visible, while in other moments mysteriously concealed?

To examine the design consequences of these issues, I will look at a number of design and fabrication aspects of a Textile Canopy project—a result of an intense, ongoing collaboration between my studio at Woodbury University and Semios by Fabric Images, our sponsoring company, the leading manufacturer in tensioned fabric architecture. The project is the perfect circumstance in which to push against the sedimented ways of thinking about the architectural envelope. In this analysis of the project I will not attempt to trouble disciplinary dualisms usually employed to talk about the architectural envelope (i.e.: skin and bones, modular and monolithic, inside and outside, etc.) but rather reveal and problematize the undecidables[1], that is, conditions that arise out of tense relationships amongst components and that cannot conform to either polarity of a dichotomy.

I will thus outline four criteria the project explores through contested relationships, conditions that allow the project to build on what Jeff Kipnis termed as one of his five important pillars. In his text "Toward a New Architecture," Kipnis denotes that "the properties of certain monolithic arrangements enable the architecture to enter into multiple and even contradictory relationships."[2] The proposed criteria is as follows: (i) Parthood & Wholeness – explores envelope ideas right at the juncture between aggregative modularity and unbounded spatial and material expansion; (ii) Rigidity & Elasticity – hypothesizes a material approach to structure and form while navigating through the boundaries of engineering elegance and fashionable shape; (iii) Pressing from Inside – mediates the traditional disciplinary categories of structure and cladding through the tectonics and representations of a puzzling bodily anatomy; and (iv) Modeling & Fabrication – discusses the tension arising out of the concurrent needs for digital interconnectivity of geometric conditions and autonomous material resolutions by regions as well as the challenges arising out of synchronizing, fabricating, and assembling the rigid and elastic components of the prototype.

(I) PARTHOOD & WHOLENESS

One of the first undecidable aspects of the project is born out of its double role as light-weight product prototype for a shading structure as well as specific campus canopy project. While the latter demands clear spans, free plan, and flexibility of use, the earlier calls for multiple spatial (and therefore material) configurations. Thus, one of the first design intentions was to find a middle ground between the homogeneity of unlimited space and more precise notions of modulated space.

Precise Parthood: Nesting the Cairo Pentagon

The organization of the modular structure for the canopy follows a multiplication of a five-point geometry, commonly known as the 'Cairo Pentagon'[3]—due to its frequent use as a method of tiling in Egypt's capital. As it proliferates, this type of tiling creates the genesis for two flattened perpendicular hexagonal tiles, each of this composed of four nested pentagons. While these are equilateral pentagons, they are incongruent figures, as their angles differ slightly, thus creating a dual semi-regular tiling.

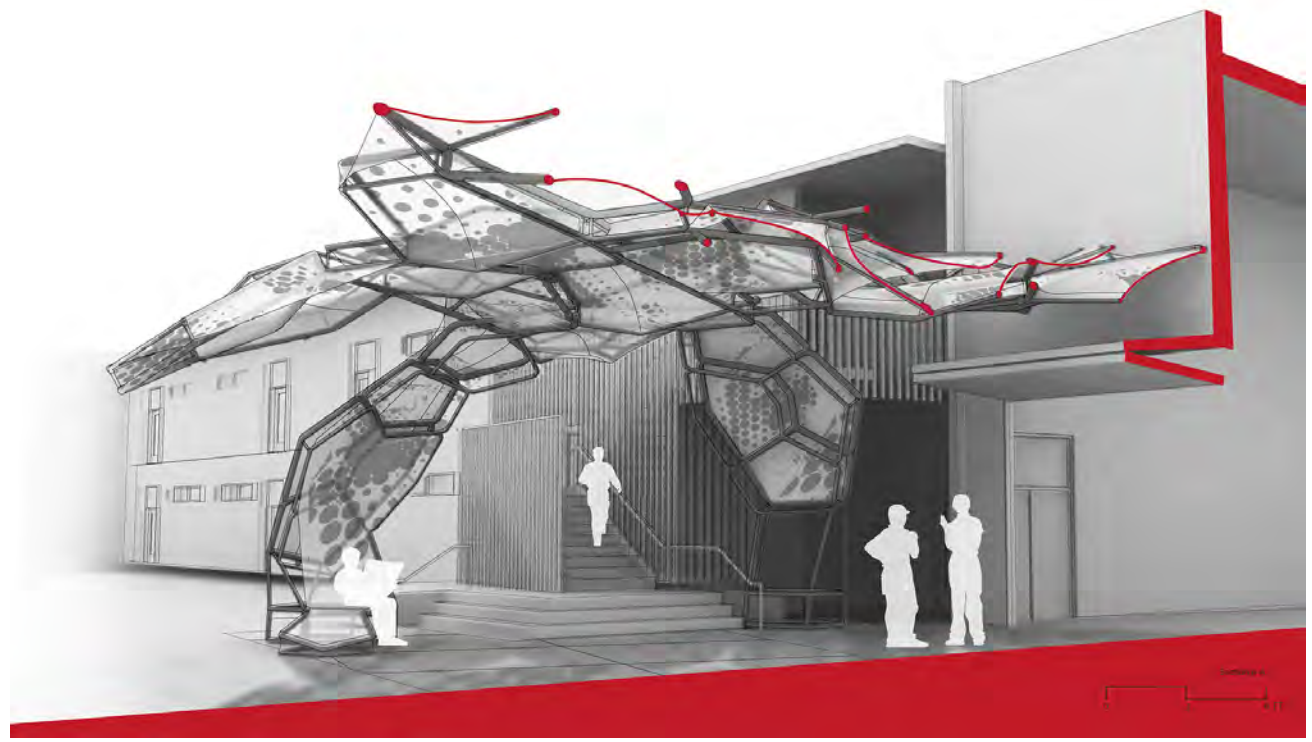
This capacity for nesting and alternating figural conditions (from five to six sided), orientation (the motif can be read indistinctly in either X or Y direction), as well as scale (hexagons are roughly four times larger than pentagons) proved a robust organizational logic for a project with both prototypical ambitions and novel formal agendas. For instance, the effect of gradually bending the structure at any of the three legs of the canopy is a product of the rotational capability as well as equilateral correspondence of the motif. In this way, ceiling becomes vaults and vaults become pillars by effortlessly folding the Cairo figures. This robust repetitive motif also allows the project to be systematically conceived as a prefabricated kit of multiple parts, achieving not only flexibility in assembly and efficiency in manufacture, but also a capacity for deconstruction, disassembly and reuse.

The repertoire of repetitive structure or form within architecture has often resulted in approaches that promote abusive serialization, resulting in a thoroughly articulated space. Steel construction has been the material vehicle for these Fordist models of mass-production, which celebrate endless repetition and regularity as well as spatial stratification. Parametricism as a form of additive versioning has introduced little to no exception in this practice: articulating the endless continuity of self-identical cellularity across an all-encompassing system all too often crystalizes into another top-down part-to-whole relationship and fixed logic, from a visual and spatial stance.[4] Thus, for a more undecidable formal and spatial envelope to exist, we required a balancing act between the hierarchies put forward by the Cairo close-packing system and some other notion of unbounded material definition.

Unbounded Jacket

A workable conceptual framework to approach this problem is from the perspective of mutable, even reversible, part-to-whole relationships capable of assimilating broader notions of spatial tactics. Materially, fabric promises physical versatility in its application as well as easiness of spatial extension, all produced with nimble plastic effects such as shrink-wrapping, stretching, pushing, draping, etc. Typologically, fabric offers the ability to work with mutant notions of the envelope,

Figure 2: Perspective section through canopy structure and existing auditorium



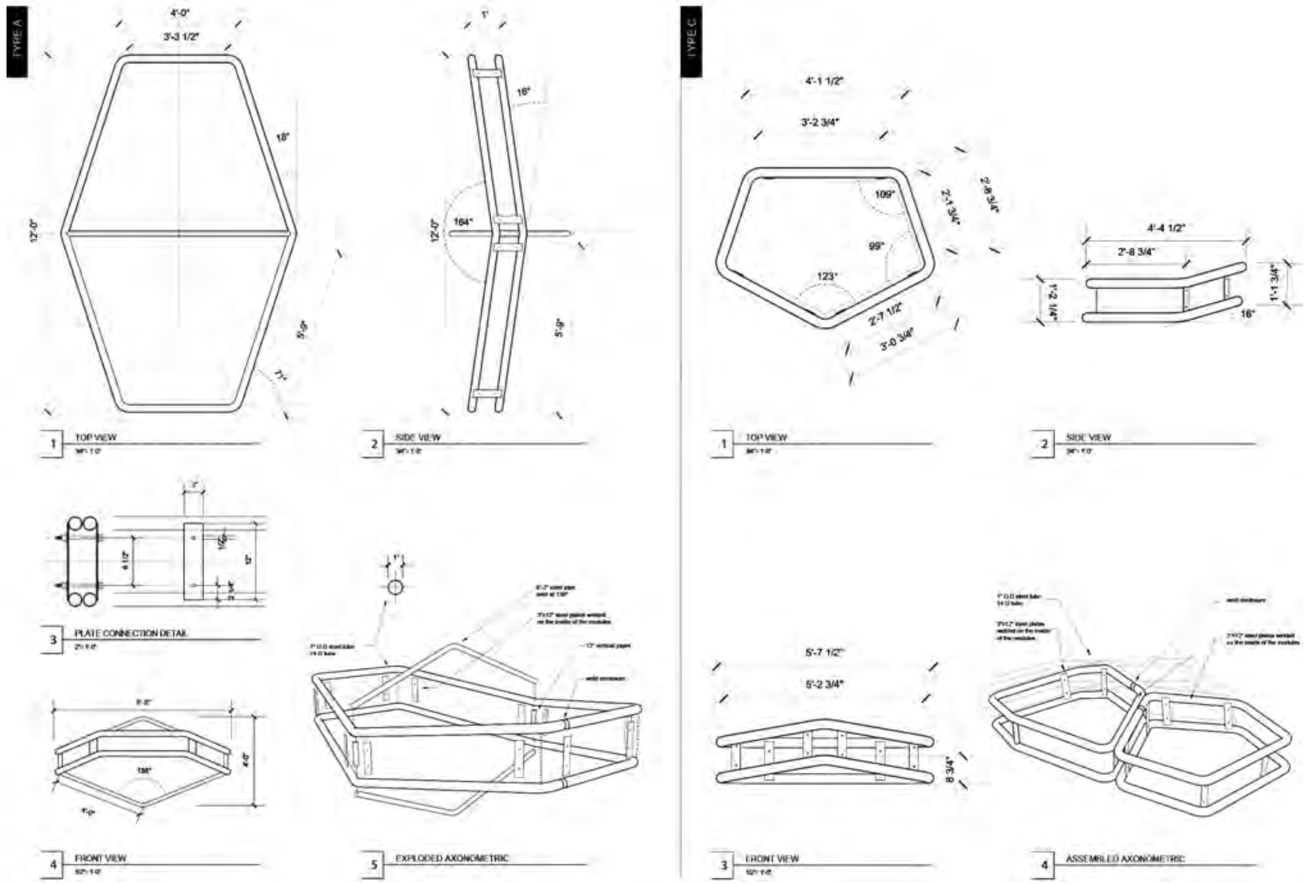


Figure 3: Shop drawings of bent aluminum tubes composing hexagonal or pentagonal structural modules

achieving hard and soft conditions as well as effects of looseness and tightness. Our renewed interest in fabric had to do as well with the degree by which new technologies—descriptions of which I will pursue in greater detail below—have pushed this polyfunctional material to behave ever more adaptively in order to achieve a wide range of building needs beyond mere passive sheltering.

Our preliminary material attitude towards fabric was to conceive of an architectural project within which a wide range of possibilities, mechanisms and procedures could work: from the immediate qualities and performances of the material—strength, durability, color, etc.—to the regulations and inflections that we as architects make on them.

Thus we pushed the textile to completely shrink-wrap the modular rigid frame, producing a range of loose and tight fits, which attach and detach to and from the structure. This range of fitting qualities reveals at times incongruences between the outer membrane and the internal frame in the form of skin excess, while in others the membrane performs much like a straightjacket. I will have occasion to elaborate on the issue of fitting below; however, I believe that the brief description above of the frictions between the modular inner structure and immensurable outer skin is where the undecidable aesthetics of the envelope rest. Moreover, by virtue of changing light conditions, the fabric produces substantial effects and visual readings, alternating transparencies and opacities; this condition makes the envelope's anatomy create several timely aliases, which at times reveal glimpses—or partial figures—of the modular Cairo spatial pattern, while in others conceal any notion of scale or order, giving way to a homogeneous, infinite, monolithic shell.

(II) RIGIDITY & ELASTICITY

Each one of the hexagonal figures that compose the Cairo pattern turns into a range of polyhedrons with varying profiles and related three-dimensional figures. The initial two-dimensional motif thus becomes more akin to a conglomeration of diamonds, imbuing the frame with crystalline or gemstone-like conditions. Each face or facet of these polyhedrons materializes into an irregular, closed 2-d figure or ring, which is manufactured with a round aluminum tube[5]; these would feed directly into the manufacturing line to be CNC bent.

Every piece of this gemstone puzzle is joined on their sides through a method called 'flat stock', involving steel plates at either side of each polyhedron that are later bolted together. Pentagons nested within hexagonal figures are selectively edited out in regions were the structure as a whole needs to reduce its weight; conversely, those modules positioned in sensible structural areas, such as the legs and their vicinity, are nested with pentagonal rings in order to prevent deformation.

Figure 4: Night view of canopy structure.

Soft Gemstone

Since Frei Otto's experiments with soap bubbles (via Gaudi) informed his studies of membrane structures, elastic materiality has been associated with the tensile: materiality shaped under structural optimization through their natural gravitational flow. According to this principle, form-finding exercises galvanized most of the formal genres in elastic envelopes toward optimal draping simulations, often resulting in familiar, eidetic configurations. The engineering elegance that encompasses the formal lineage of surface structures relies on the principle of catenary curvature: is the natural curve that a cable or chain will adopt if suspended by its two ends. The resulting geometry is the corresponding ideal form for a cable resulting in uniform axial tension forces (or axial compression forces for an arch).[6]

Set apart from the historical envelope classifications of skeleton and skin, a surface structure's most important spatial and material characteristic is "the coincidence of the inner space and external form being almost identical; the form can be read from both inside and out."[7] The indexical nature of the structure from within and without precludes the irregular poché, as well as interstitial space or cavity. Under these assumptions, any thing constituting a disruption, break, or form of rupture disrupts a membranes' capacity for a pure structural reading. Geometrical simplicity, in structural principles based on natural laws, is essential.

Bursting Margins argues for a hybrid approach to structure, producing formal configurations that break a single ideal catenary path into many sub-segments. This results into a poly-curved shell, with fabric sagging into several curved surfaces following the principle of the catenary. What's stimulating about this approach is not only the ability of the poly-curved membrane to break spatially the scale of the sheltered area, but the textile ability to tighten the frame and force it to work under compression, much like a corset to the body. Fashion anachronism aside, the corset has a dual medical purpose, as people with spinal problems, such as scoliosis or internal injuries, may be fitted with a form of corset in order to immobilize or protect the torso.[8] In the same way, the ceiling and column moments of the canopy are held together by the membrane.

This is a clear alternative to the engineering elegance underlying natural shaping methods for structures utilized by Otto and others: a more aggressive shaping process that spreads the pressure onto the inner bones and holds the canopy figure erect through a precise, tailored fit. Imported from fashion, this model of elasticated yet stiffened architectural garment provided a more dynamic conceptual framework of mutual responsiveness between form and structure.

PRESSING FROM INSIDE

Bursting Margins positions the envelope as a kind of architectural hernia, where protrusions of organs (often internally contained by the cavities of the architectural body) re-surface, so that the anatomy of such a body is pressing from inside—or bursting. In trying to describe these sensibilities of his own work, British sculptor Henry Moore employs the allegory of "clenching your fist and seeing your knuckles pushing through the skin."[9] Moore went on to explain that this is not just another shaping force, but rather an overall sense that the vitality and strength of the sculptural body is given from inside.[10] Moore's admiration for the sense of pressure from within human figures, such as bones pushing through the surface, can be seen in many of his sculptures, alternating moments of fluidity with boney tautness.

The attraction for us is in the vanishing or dissolving qualities of emerging profiles, and the conceptual idea of a skeletal structure poking from the inside. This inside out approach to form is what guided our envelope studies. What's stimulating for us is not only the ability of the poly-curved shell to break spatially the scale of the sheltered area, but also the appearance of formal regions delimited by emerging—and dissappearing—profiles and fall-off silhouettes in the form of ridges, rims and creases. This is a direct product of the geometric motifs that compose the rigid frame pushing through the skin. These moments of rupture—or bursting!—play a pivotal, topological role: an interaction or friction of systems that would otherwise be kept separate.

It was the modern Italian architect Luigi Moretti who first underscored this condition of profiles in architecture in his 1951-2 essay "The Values of Profiles."[11] In his analysis of Moretti's work, Peter Eisenman argues that "the issue of profile is articulated through both hard edge and figured form."[12] Eisenman goes further and calls attention to the thematic quality of profile in Moretti's work and suggests that it "becomes more than just the edge of a three-dimensional volume and instead serves to question the clarity of boundaries

Figure 5: One-to-one scale prototype of rigid structure

between edge and volume,"[13] thus adopting a role as "marker of undecidable relationships."[14]

For our canopy, profiles exist in one of two ways: as internal edges or as contours. Both of them mediate the intricacies of the 3-dimensionally manipulated Cairo pattern and relaxed fabric moments. Yet, internal edges exhibit vanishing qualities in the form of inchoate fall-offs, which at times partially expose figures of the inner frame, while in other ones peculiarly mask them. This reminds us of Eisenman's argument of the unstable boundary existing between edge and volume, and shall we add, between 2-d graphic features and 3-d modeling. Alternatively, contours possess mutant characteristics as well, but of a slightly different topological nature: they transform from straight-line traces of the firmly shrink-wrapped polyhedrons to the parabolic transitions fabric creates when it naturally flows in moments of detachment from the frame. The result is a series of compound curves full of turns, exhibiting both segmented and curvilinear geometric qualities. In sum, the elastic aspect of the canopy envelope becomes a site of augmentation and concealment of its modular inner skeleton, like collaged boney traces of an edged body about to burst.

(IV) MODELING & FABRICATION

From a digital modeling stance, the complexities of the poly-curved shell demanded digital modeling techniques that provide an easy access to topological change and disciplined relaxation—hardly possible with the simplistic and uniform constitution of NURBs surface logic. Instead, techniques in interactive simulation through Kangaroo Physics and other Subdivision Surface modeling techniques through T-Splines presented an effective alternative to conventional NURBs modeling as they allow for draping algorithms and overall digital continuity of surface conditions while at the same time inducing greater flexibility in the introduction of creases, wrinkles and other fashion-like detailing.

I have briefly referred above about the fabrication and assembly of the bent aluminum tubes that together compose the frame; I will deliberately avoid elaborating in depth about this component of the project as I believe the technology involved has been extensively documented in many tubular steel or aluminum structures. I will, however, dedicate this fourth section to discuss the material and assembly techniques involved in manufacturing the flexible membrane as well as attaching it to the aluminum structure, as I believe they are the ones that present the most complexity and challenge as well as produced the customized identity of the project.

The chosen exterior material is a polytetraflouroethylene (PTFE) membrane, which is able to provide shade during the day and a translucent figure at night, while the interior membrane will be made of softer linen-like fabric. Because PTFE is tough and hard to tension in long lengths, we faced the necessity of breaking the poly-curved membrane into several patches along predetermined seams that coincide with trajectories dictated by the Cairo motif (fig. 1). For the desired taut effect, these smaller patches would be laced tightly to the aluminum tubes via metal eyelets arrayed along the edges.[15] Through scaled analogue models we were able to understand that at this rate of connectivity between the membrane and frame, we would be able to maintain a degree of deflection in the fabric caused by the weight of the material.

The patches of fabric will be also outfitted with edge zippers in order to connect them together post tension. This assembly method was preferred due to its ability to exacerbate the seaming moments of the membrane, adding a new degree of hierarchy to the edges that exhibit boney tautness in the 3-d model. The zipper effect would thus add a garment-like quality to the membrane, yielding a higher level of design elegance while reinforcing some of the figural graphic trajectories that are fundamental to the project. Along the same line of thinking, LED Strips would occupy the space between the outer and inner membranes and copy some of these networked trajectories, allowing the hollow cavity to glow at night and project out the thick Cairo motif. By virtue of multiple projecting sources, structural patterns and seams would thus augment their intricate graphic presence and produce sophisticated atmospherics effects.

Figure 6: Interior view of shaded area looking towards auditorium

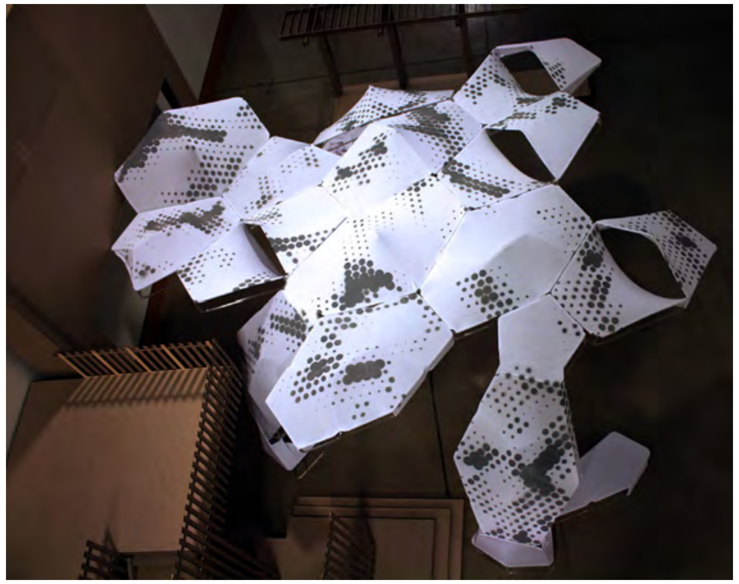


Figure 7: Aerial view of shading structure.

There is a reason, however, why the fabric of the project appears in pictures of the models up until a certain scale. At the one-to-one scale mockup that links one of the vertical and horizontal portions of the modular frame we encounter a few construction challenges when trying to attach the membrane onto it. Despite careful shop assembly of the many curved pipe elements[16], tolerances with the fabric skin require the use of a more advanced 3D survey technique unavailable to us at the moment in order to measure precise work-point locations on the frame, which was pre-assembled at the shop, disassembled for transport and reassembled on site. The complexity of design, with irregular shapes of patches, posed the difficult challenge of tensioning each of them into place through the lacing mechanism while simultaneously minimizing any wrinkling. Future mock-ups of the canopy project would inevitably necessitate a higher degree of synchronization amongst flexible and rigid components in order to yield a more precise level of correspondence that accounts as much for the attached, taut moments as for the semi-detached, looser ones.

CONCLUSION

There is always a mystifying element in elastic forms of growth. One possible explanation has to do with the fact that there is both maintenance and destabilization of the assumed corporeal aspects of the enveloping object or body, as much as there is restraint on an alleged second, enveloped object/body. A mutant typology, I've been arguing throughout the paper, is born out of this condition. However, the mutant not only embodies the ever changing boundaries between the distressed and the fluid; the discrete and the continuum; or the loose and the taut, but more remarkably between the different disciplines: in our case, architecture, fashion, and technology. The emerging associations between profiles and zipped seams, envelope and corset, structure and patterns, shape and tailored fit, etc., are just a few examples of those unstable disciplinary boundaries.

It seems paradoxical to argue that the strength of a project arises out of instabilities or incongruences. The late architectural critic Robin Evans reminds us, however, that "from the point of view of the architect seeking firmness and stability, the best geometry is surely a dead geometry"[17] as its elements "have been pretty well exhausted as subjects of geometrical enquiry."[18] Thus, the discourse of geometric representation requires, for Evans, some form of projection. In our canopy, it is in the passages between profile to surface or volume, or motif to relief where geometry has been activated, and where an alternative notion of envelope begins to unfold.

Projective representation is thus crucial to this discussion. It is particularly so at a time when a wide array of computational design practices seem to have rushed towards performance based optimization, unequivocally locking geometry from its inception. Take as an alternative example our canopy project: there is a tension between the measured side of the structure, with its marked sequence or rhythm, and the unquantifiable expanse of the membrane. We cannot completely see the internal structure in its full appearance, as some fragments are revealed while others recede into inscrutable depths. So in a sense what we see is part real part imagining of the form. In between we have to make a visual and conceptual leap of faith to interpret the spatial complexities of the whole. Throughout that process, whether you see a *hat* or a *boa constrictor digesting an elephant,* has more to do with driven aesthetic enquiry than with optical precision.

ENDNOTES

1. For a thorough explanation and theorization of undecidability in architecture, see Peter Eisenman, *Ten Canonical Buildings: 1950-2000*, ed. Ariane Lourie (New York: Rizzoli, 2008).

2. Jeffrey Kipnis, "Towards a New Architecture," in *AD: Folding in Architecture*, ed. Greg Lynn (London: Academy Press; Revised Edition, 2004) 59.

3. It is also called MacMahon's net after Percy Alexander MacMahon and his 1921 publication *New Mathematical Pastimes*. Alternatively, the British mathematician John Horton Conway refers to it as a '4-fold pentille'.

4. For an in-depth discussion on the issue of spatial and visual homogeneity/heterogeneity as it relates to parametricism, see my essay "Heterotopic Speciation [Theorizing an Alternative Parametric Syntax]" in *Proceedings of the 101st Annual ACSA Conference: New Constellations New Ecologies*, ed. Ila Berman and Edward Mitchell (2013) 443-52.

5. Aluminum was chosen as the structural material for the structure due to its high strength to weight ratio. The pictures shown of the current mock-up of the project, however, employ steel rather than aluminum due to the available manual craftsmanship involved at the time of its production.

6. Remo Pedreschi, "Form, Force and Structure", in *AD: Versatility and Vicissitude*, ed. Michael Hensel and Achim Menges (London: Wiley, 2008) 14.

7. Remo Pedreschi, "Form, Force and Structure," 13.

8. C. Willett Cunnington and Phillis Cunnington, *The History of Underclothes*, Dover Fashion and Costumes Series (New York: Dover Publications, 1992).

9. Dorothy Kosinski, ed. *Henry Moore: Sculpting the 20th Century*, ed (New Haven and London: Dallas Museum of Art/Yale University Press, 2001) 43-54.

10. Dorothy Kosinski, ed Henry Moore, 33-42.

11. Luigi Moretti, "Valori della Modanatura" in Spazio 6 (1951-2). Translated by Thomas Stevens as "The Values of Profiles," in *Oppositions 4: A Journal for Ideas and Criticism in Architecture*, eds. Peter Eisenmann, Kenneth Frampton, and Mario Gandelsonas (New York: The Institute For Architecture And Urban Studies, 1974) 109-39.

12. Eisenman explains that "Profile is the edge of a figure—in other words, how a surface in architecture meets space: the edge of a volume seen against the sky is a literal profile." Peter Eisenman, "Profiles of Text: Luigi Moretti, *Casa Il Girasole*, 1947-50" in *Ten Canonical Buildings*, 26-49.

13. Eisenman, "Profiles of Text," 26-49.

14. Eisenman, "Profiles of Text," 26-49.

15. The only exceptions to this are the boundary patches, which are directly zipped to the frame via pocket sleeves running along the edges.

16. At the moment of construction of the exhibited one-to-one scale mockup, only manual tube bending technology was available to us; thus the margin of error within the frame could have slightly increased the size of the framing and render the membrane patches tighter than they were originally planned to account for, thus demanding a larger force to tension them at the risk of tearing the fabric.

17. Robin Evans, *The Projective Cast: Architecture and its Three Geometries* (Cambridge and London: The MIT Press, 2000) xxvii.

18. Evans, *The Projective Cast*, xxvii.

PROJECT CREDITS

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Photos and Illustrations

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