THE BRIDGE

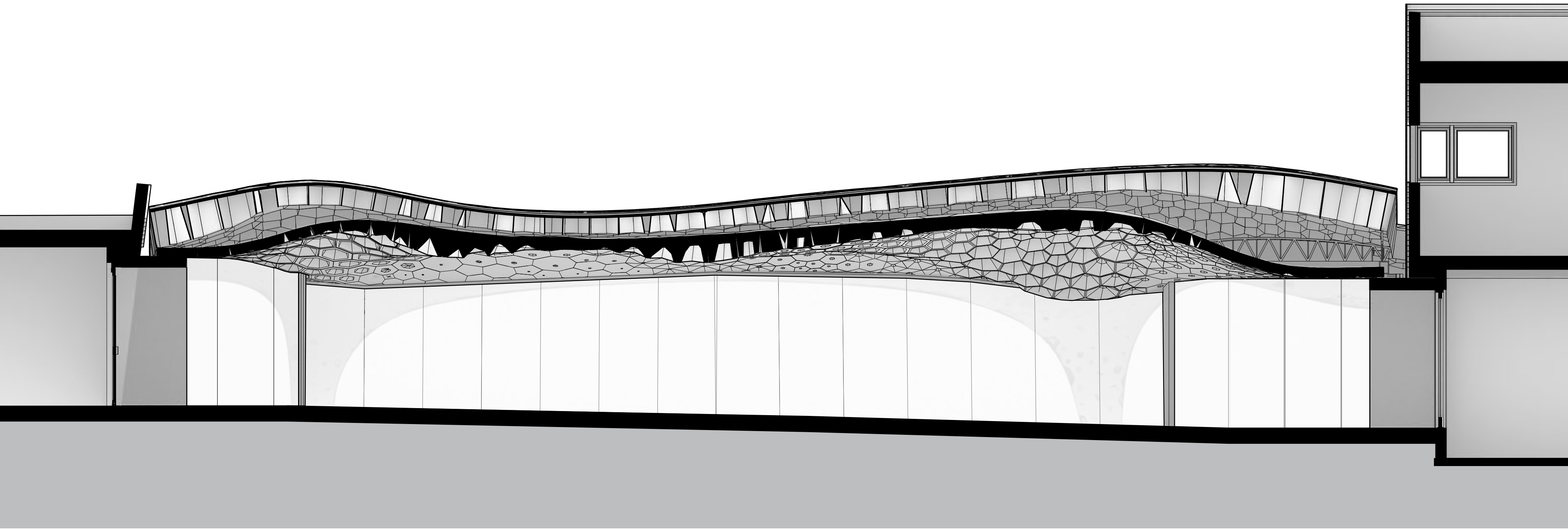
AIA TAP AWARDS 2015

OVERVIEW

The D-Bridge is a yet-unbuilt architectural project and experimental structure that serves as an extension to a private gallery and residence in the Philadelphia area. Our office worked in close collaboration with facade and BIM experts, as well as several other fabricators and consultants in the greater Philadelphia region. A design team of between two and three worked on this project, primarily in the Summer of 2014.

It is our intent to present the Bridge as a case study in small-office technological design and information management. The desire to design and construct a project like the D-Bridge grew from a BIM-like philosophy that is a founding ethos of our office. The knowledge and tact to execute the project grew from close collaboration with contemporary BIM experts, as well as adopting tools and expertise from the burgeoning open-source community around Rhino and Grasshopper.

We were thereby able to transform our primary tool for geometric control into our organizational system for the entire project–which we used in totality from formal experiments, to visualization of data, to coordination and design of building systems, to fabrication management, to delivery logistics and construction scheduling. All managed from within the software we already use for 3D modeling and drawing.



The D-Bridge (Bridge) is a single-story, single-room, 1200SF building that acts as an enclosure along a path between an existing residence and an Art Gallery. The building is a thickened shell with canted glazing and six door openings—it is environmentally controlled, and it provides both a programmatic link between living and gallery spaces, and a series of smaller, more intimate porch-like spaces around the boundaries of the buildings.

The core feature of the Bridge serves as both its form and structure—in this case, over 1000 laser-cut, folded cells made from flat sheets of stainless steel (voxels). Each voxel is easily handled by an individual, starting around the size of a shoebox (8"x8"x10"), up to about the size of a lawnmower (32"x32"x14"). The voxels form a shell, a pelt of sorts, which wraps the enclosed volume under a complex honeycomb of tightly-interlocking, riveted-together metal parts. The interior surface of this shell was the primary geometric component onto which all other geometric controls were grafted and grew. The edges of the shell fit snugly into the details of the adjacent buildings, and it carries its load down to three legs which touch down in the surrounding meadow. The overall shape of the shell was finely controlled for its external connections, its internal constructability, its structural capacity, the interior and exterior views it provided, and the experiences inside and on site that it engendered.

CULTURAL CHANGES

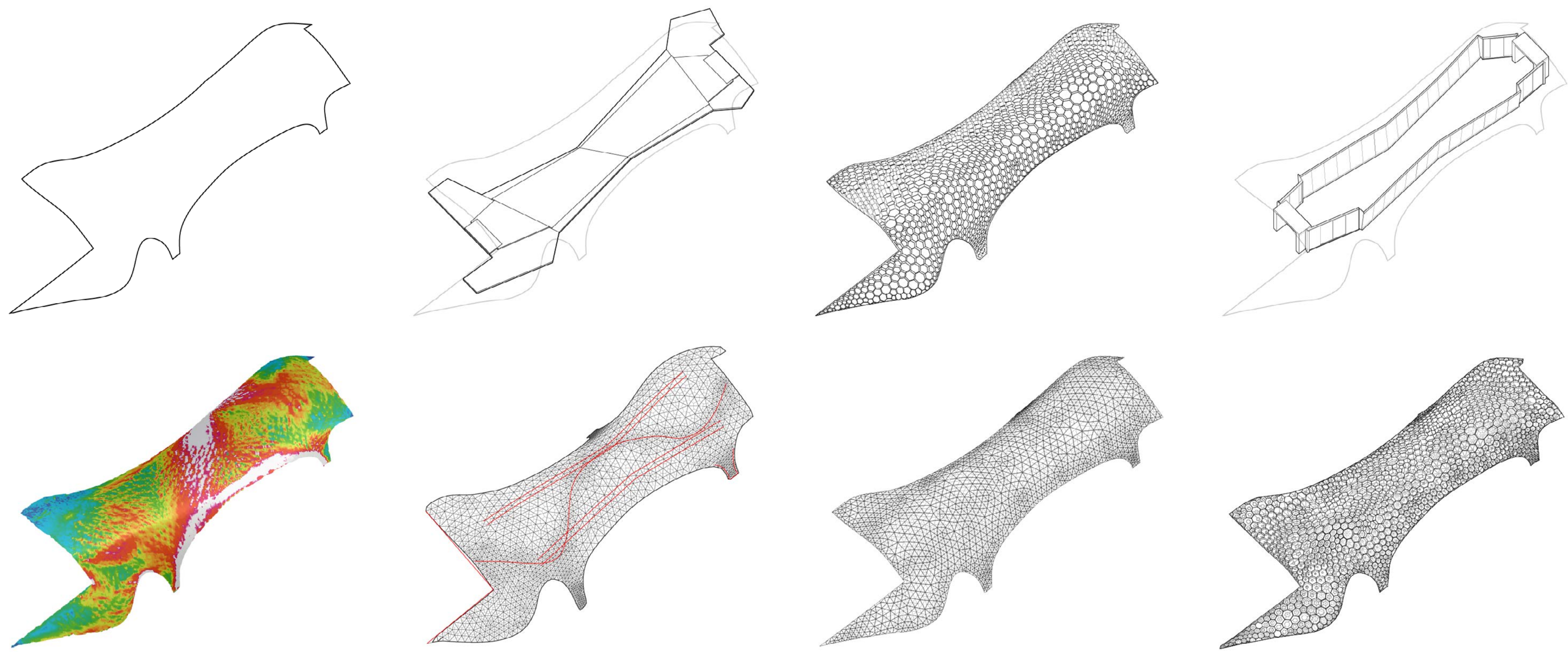
In this project, we developed cultural changes in practice, in which we were able to engage everyone involved in the project in a way that was consistent with a set of principles we, and the client, cared about in the beginning of the idea.

We were able to convince our collaborators, often (usually) in positions of assuming more risk than us, that the project could keep moving forward despite ongoing uncertainties that were still in development. This marks a change in our relationships with collaborators.

By being robust about developing the engine for BIM in Grasshopper, and by being rigorous about providing constant material and maps about our process and goals to our partners, we were able to create comfort zones where there normally were none.

Another important cultural shift we felt in this project was the communication and collaboration with the online community of individuals developing the Grasshopper platform.

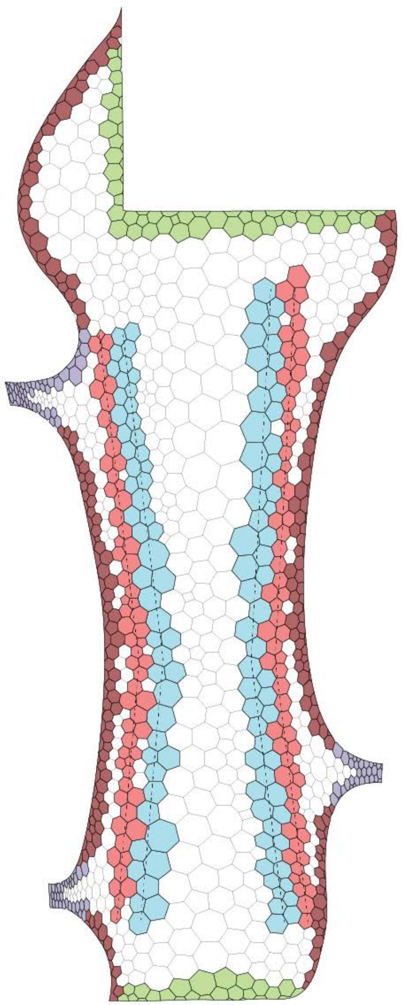
Our work built directly on the work of Grasshopper's developers, following closely with the content that is released for free online, and talking openly about our work with the community of mutually interested people on the Grasshopper forum site.

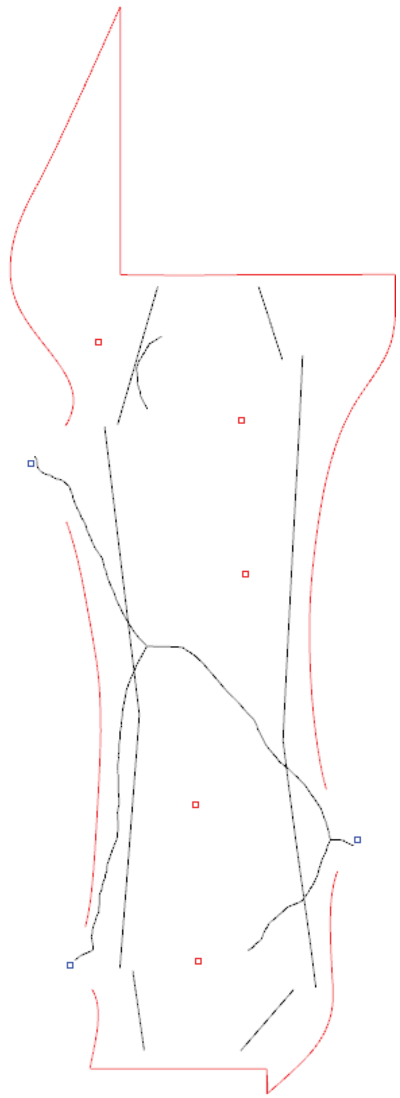


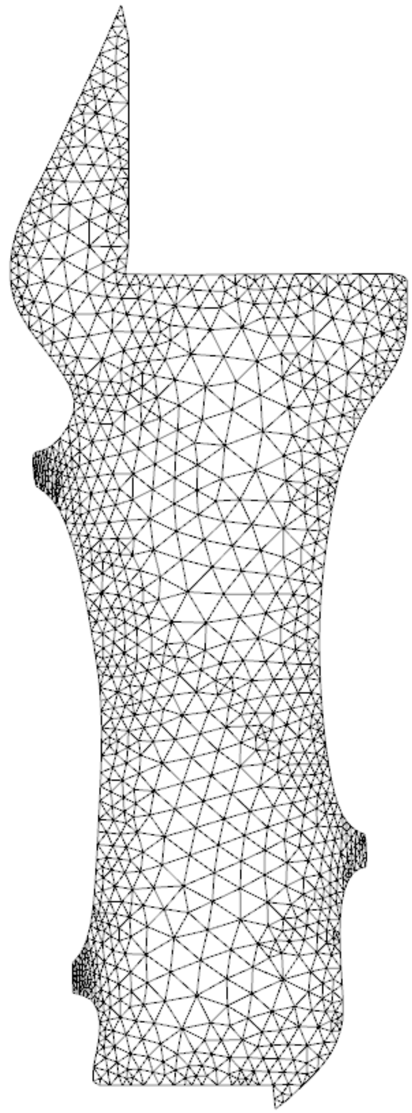
ON GEOMETRIC CONTROL

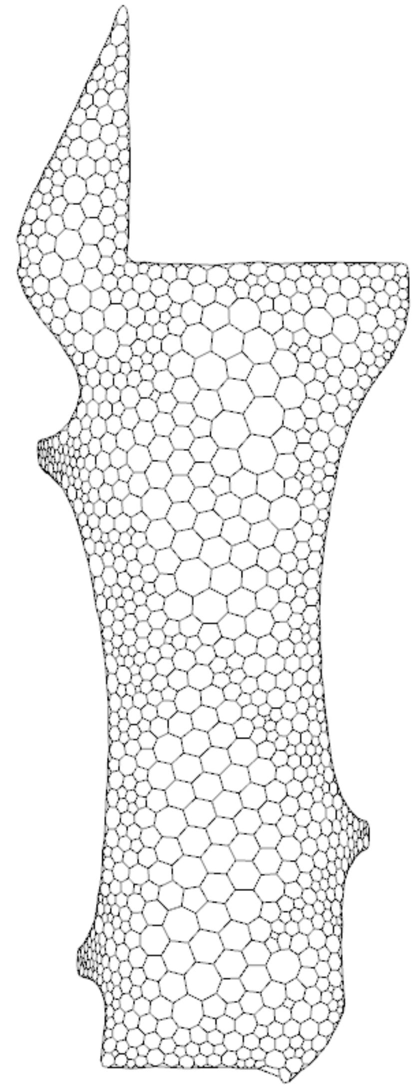
When we speak about geometric control in the Bridge project, we mean both the act of generating and manipulating the shapes of the model, and also the hierarchy of data relationships that depended on that geometry. This concept is the basis of a BIM system–what made our process special was the extent to which we tied almost all design components and outputs back to the base geometric process.

This primary geometric control is in our case a scripted process in Grasshopper that is adopted from work that is just being developed in 2014, and which is free online for anyone to use. These scripts form part of the substance of what is now the Kangaroo Physics engine, a plug-in for Grasshopper that has already exhibited amazing potential in both architectural design and engineering.







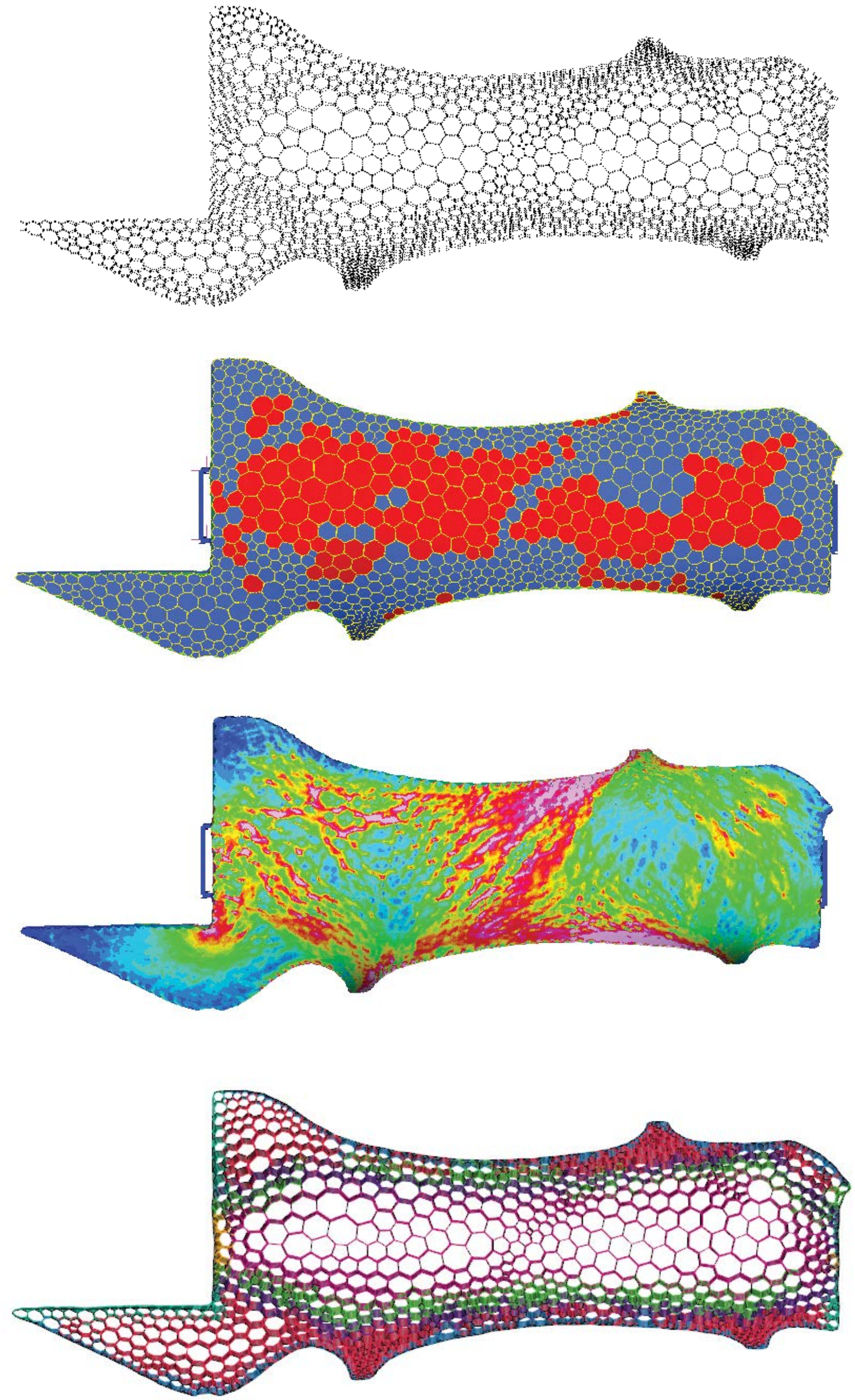


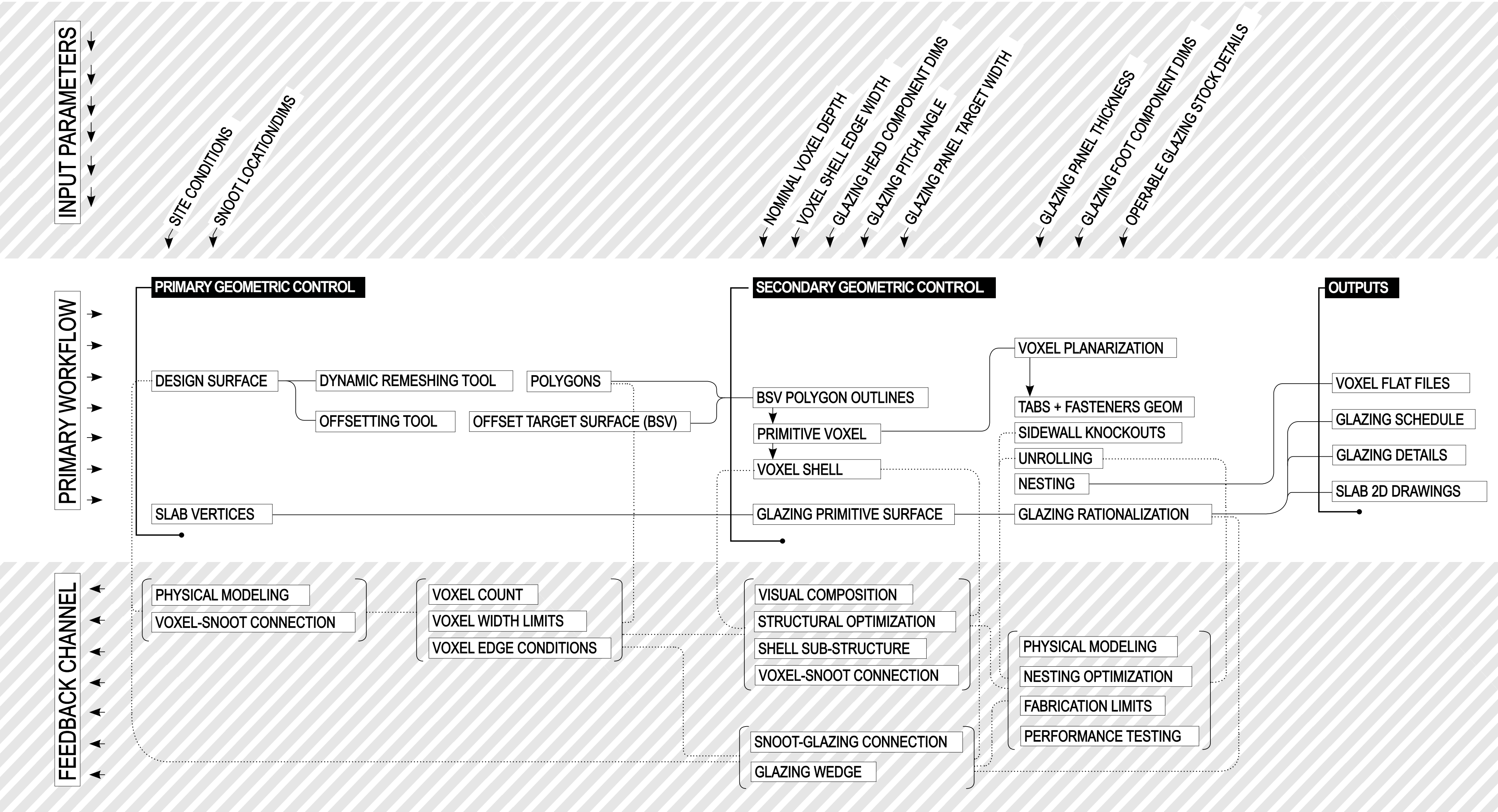
ON GEOMETRIC CONTROL, *continued*

That script takes a mesh geometry and simulates forces on its vertices to reshape the packing of the mesh. These forces are behind what is known as a "circle packing," a well-researched mathematical problem that can be visualized as the optimal tight packing of circles into a 3D surface. The circle-packing script, as adapted to our design intentions, has two very important functionalities. First, it allows us to specify regions of more densely or loosely packed parts. Then, it pulls those parts into the best-balanced spacing possible within our constraints. These two functionalities were extremely important, and the crux of the power of the BIM engine driving the project.

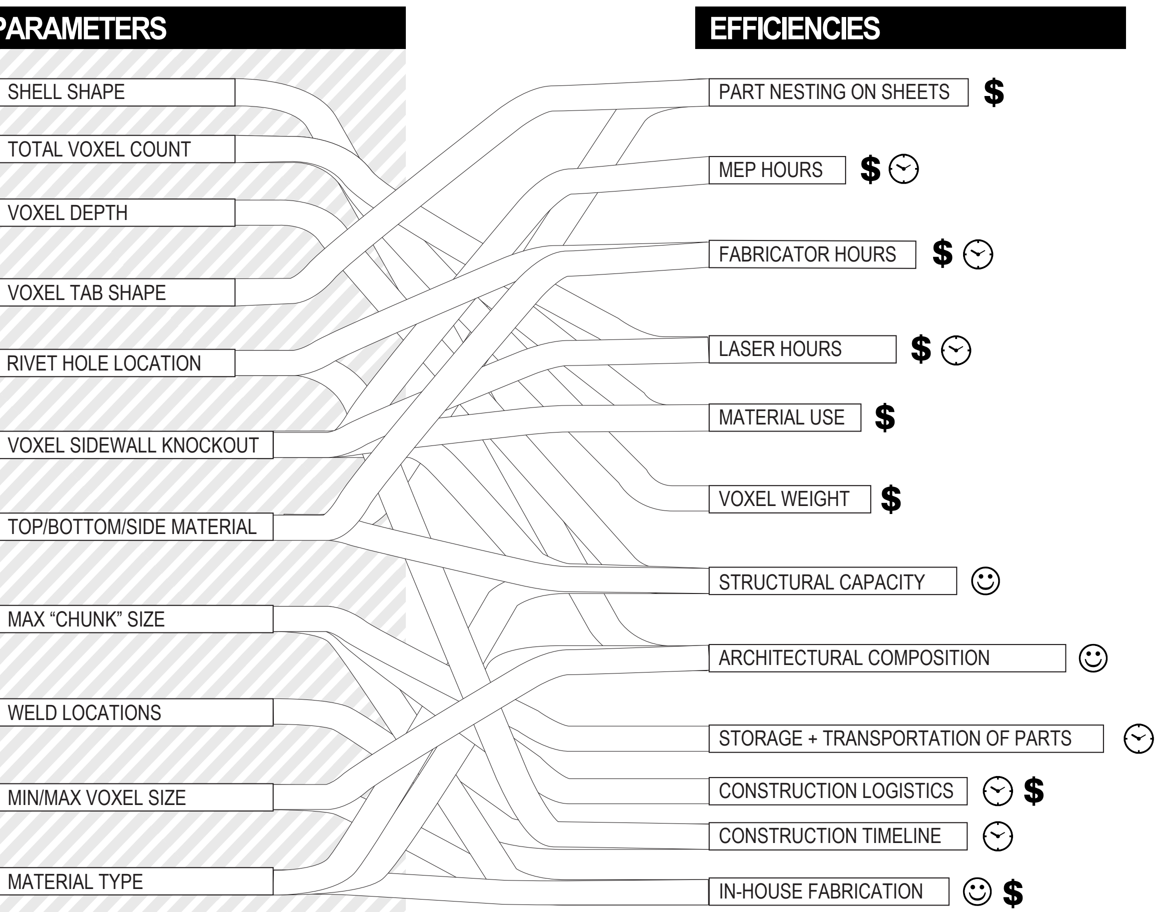
The latter quality, the balanced spacing, allowed us to improve the structural properties of the shell in broad strokes, toward the requirement of it being supported by the metal voxels alone. The former quality, the regional densification, also had structural consequences–but more importantly, it allowed us to adapt the packing of the shell to a comprehensive set of other constraints on the building. This packing informed the efficacy of the insulation and waterproofing systems for the shell, provided detailed paths for air conditioning ducts and diffusers, met the glazing line and roof edges structurally as a series of stiffened plates, and created a highly diverse environment of visual effects on the outer/under surfaces of the shell.

Going further, we linked material properties, costs, and fabrication logistics from our partners into the BIM engine as well.   This we called the secondary geometric control. Having this layer of control allowed us to get instant feedback on how changing the geometry slightly could effect substantial changes in cost, time, and feasibility.   This extended even to the physical logistics of on-site equipment and ease of constructability–this is to say, we used the geometric control to guide the design of the Bridge into a set of parts that was within the specific cutting, storage, shipping, and building capabilities of each of our partners (including using the fabrication resources of our own office).





WORKFLOW MAP



BENEFITS OF BIM METHOD

We were able to adapt and internalize the model management work that normally would have been billed to consultants. This helped us clarify all parties' scope, while keeping everyone connected and open to bigger conversations about design and data. This spared the project costs of costs on fees while creating an environment to learn.

We were able to alter material specifications and assembly plans to adapt to the capabilities of fabricators. This allowed us to significantly reduce estimates on construction by working within size constraints that alleviated the need for large jumps in scope and price–such as bringing heavy equipment on site, or keeping builder teams small to handle building parts.

We tied the structural analysis and geometric packing of the shell tightly in the BIM model. Then, tying the outputs from the model to information on costs from fabricators, we were able to see live updates on cost, and fine-tune changes in the shell that could see large drops in cost. We were able to cut some early laser cutting estimates in half.

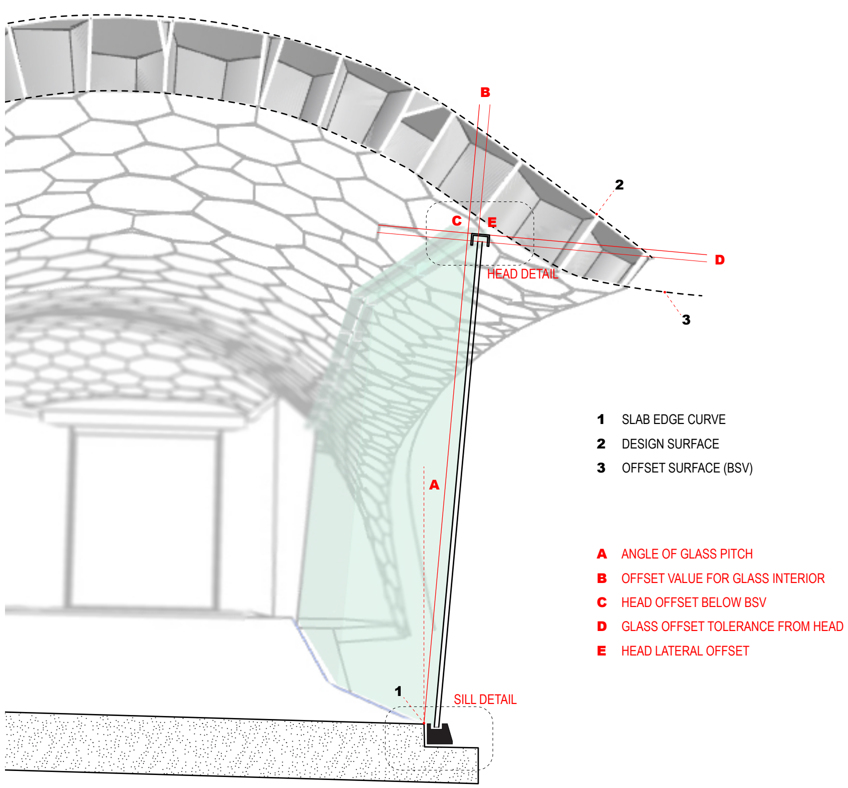
We recreated the functionality of other softwares (used by fabricators) like Solid Edge in Grasshopper. So, instead of solving the problem in terms of data interoperability, we made our BIM process speak directly in the language of the fabricators' tools–cutting out the need for back-end work on software on the fabricators' end. We reduced their scope, and thus costs.

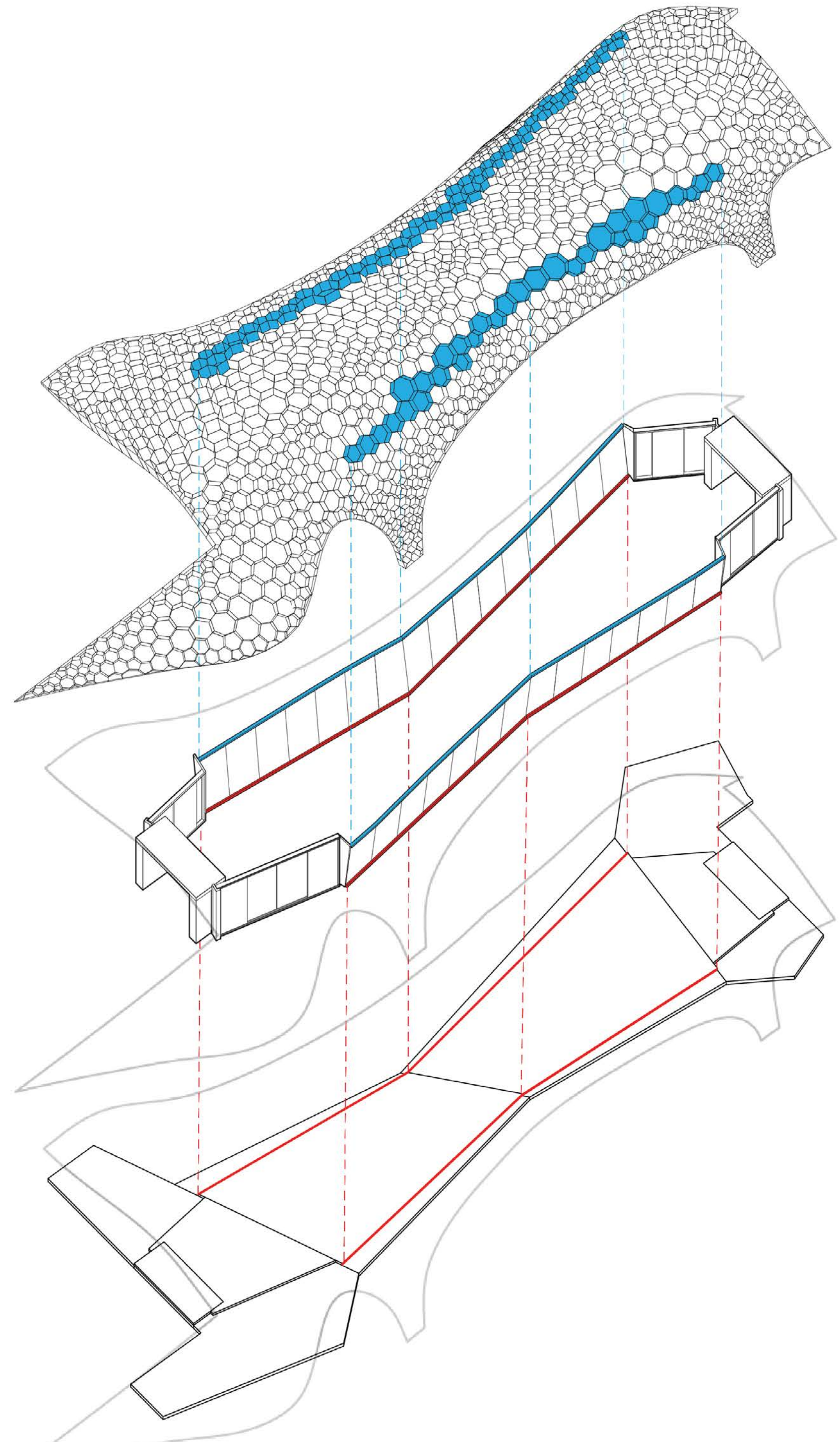
PROCESS CHANGES

We consider our BIM environment, created and driven in Grasshopper, innovative for several reasons.

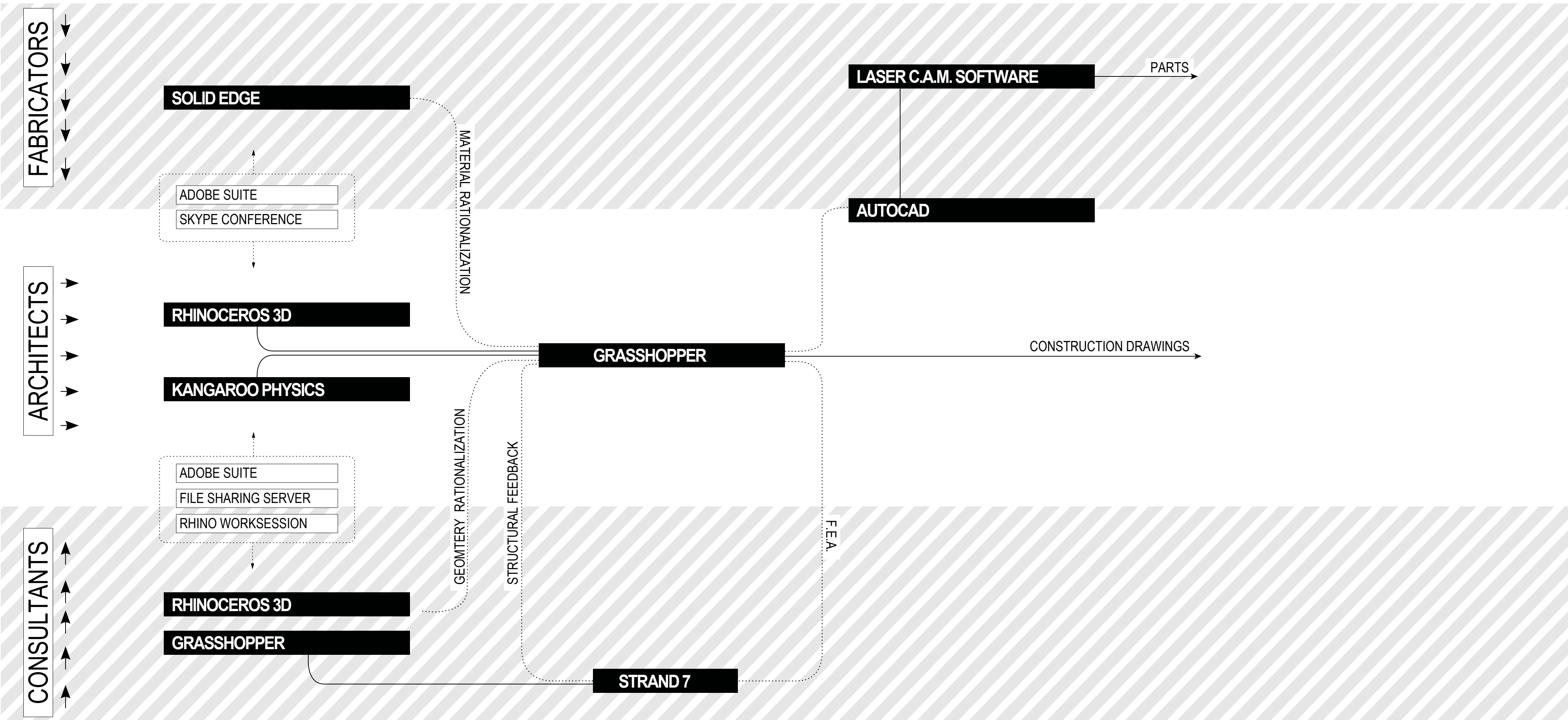
It has the functionality expected in other BIM workflows—of controlling construction drawings and schedules directly from the front-end manipulation of simple parameters in a digital model. This is manifest in the direct link between the base geometry (of the slab, and shell), and documents like the final glazing schedule.

For a small practice, we believe this is innovative, in that it appends the type of BIM power wielded by larger teams onto a platform (Rhino) that is in common use and within the grasp of individuals. We were able, with a team of two, to communicate fluently in the languages of both Front Inc. and our client, with drawings and data that were flowing from Grasshopper.

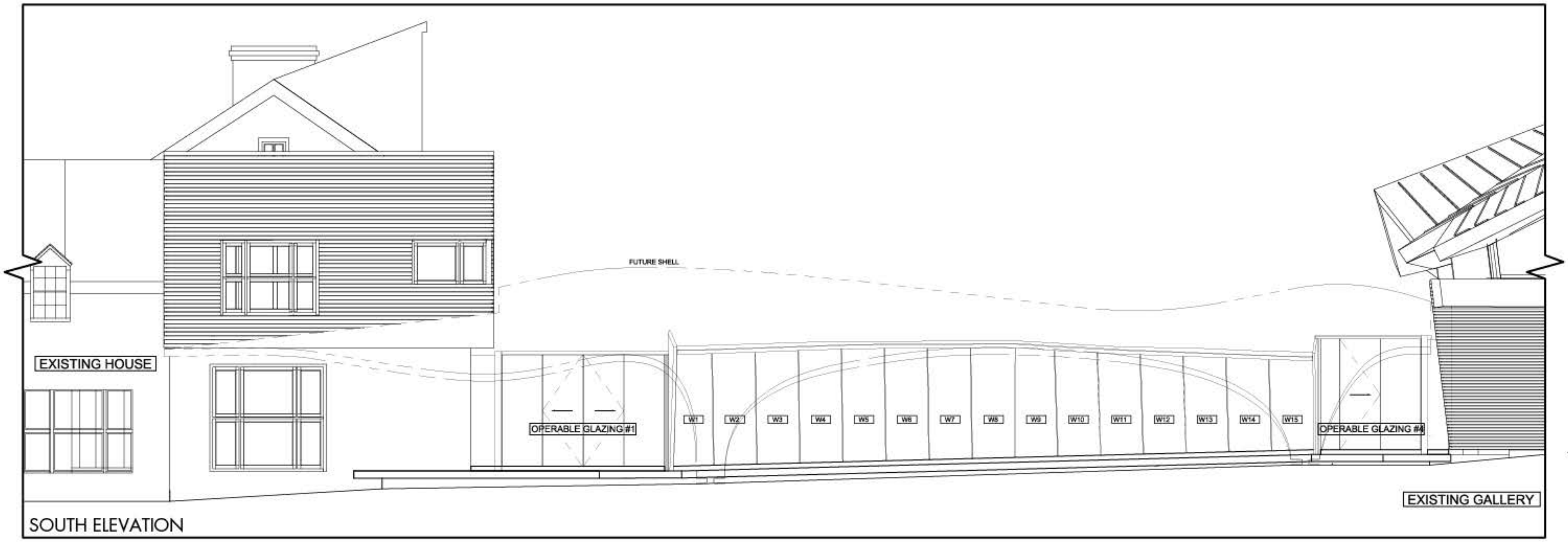


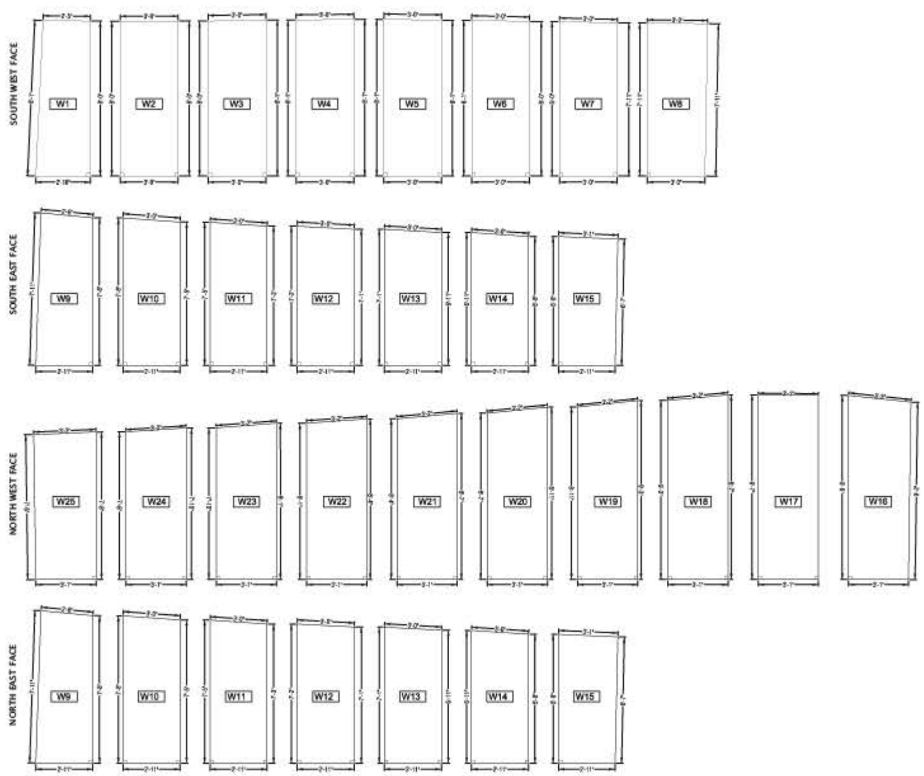


Deeper, at its roots, ***the BIM system is designed with the expectations of massive design and engineering changes along the way***—changes that can trace backwards through the workflow, reinforming and re-actualizing the project as we went. This, to us, is the core philosophy of BIM. We went further, and used the D-Bridge to test some of these "holy grail" notions of BIM (an ***Architecture Butterfly Effect***), and to try to test the limits of automation and parametric data management for a small practice, in a project of reasonable scale and scope.



DATA EXCHANGE MAP


FUTURE SHELL
EXISTING HOUSE
OPERABLE GLAZING #1
W1
W2
W3
W4
W5
W6
W7
W8
W9
W10
W11
W12
W13
W14
W15
OPERABLE GLAZING #4
EXISTING GALLERY
SOUTH ELEVATION


SOUTH WEST FACE
W1
W2
W3
W4
W5
W6
W7
W8
SOUTH EAST FACE
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W11
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NORTH WEST FACE
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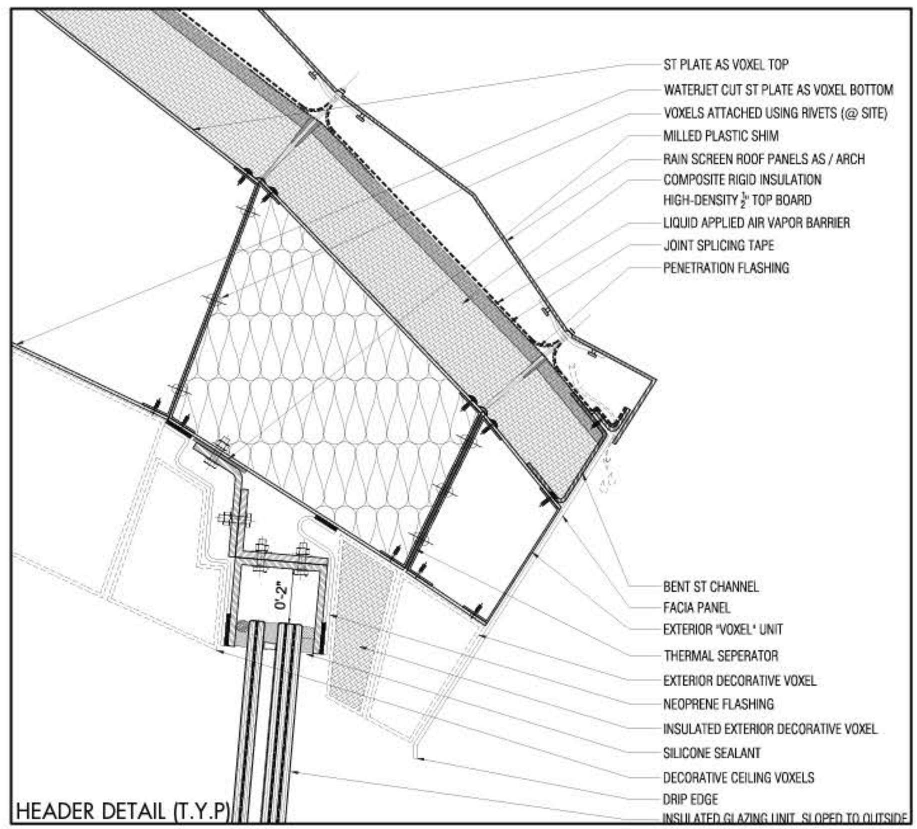

ST PLATE AS VOXEL TOP
WATERJET CUT ST PLATE AS VOXEL BOTTOM
VOXELS ATTACHED USING RIVETS (@ SITE)
MILLED PLASTIC SHIM
RAIN SCREEN ROOF PANELS AS / ARCH
COMPOSITE RIGID INSULATION
HIGH-DENSITY ½" TOP BOARD
LIQUID APPLIED AIR VAPOR BARRIER
JOINT SPLICING TAPE
PENETRATION FLASHING
0'-2"
BENT ST CHANNEL
FACIA PANEL
EXTERIOR "VOXEL" UNIT
THERMAL SEPERATOR
EXTERIOR DECORATIVE VOXEL
NEOPRENE FLASHING
INSULATED EXTERIOR DECORATIVE VOXEL
SILICONE SEALANT
DECORATIVE CEILING VOXELS
DRIP EDGE
INSULATED GLAZING UNIT, SLOPED TO OUTSIDE
HEADER DETAIL (T.Y.P)

BIM OUTPUTS

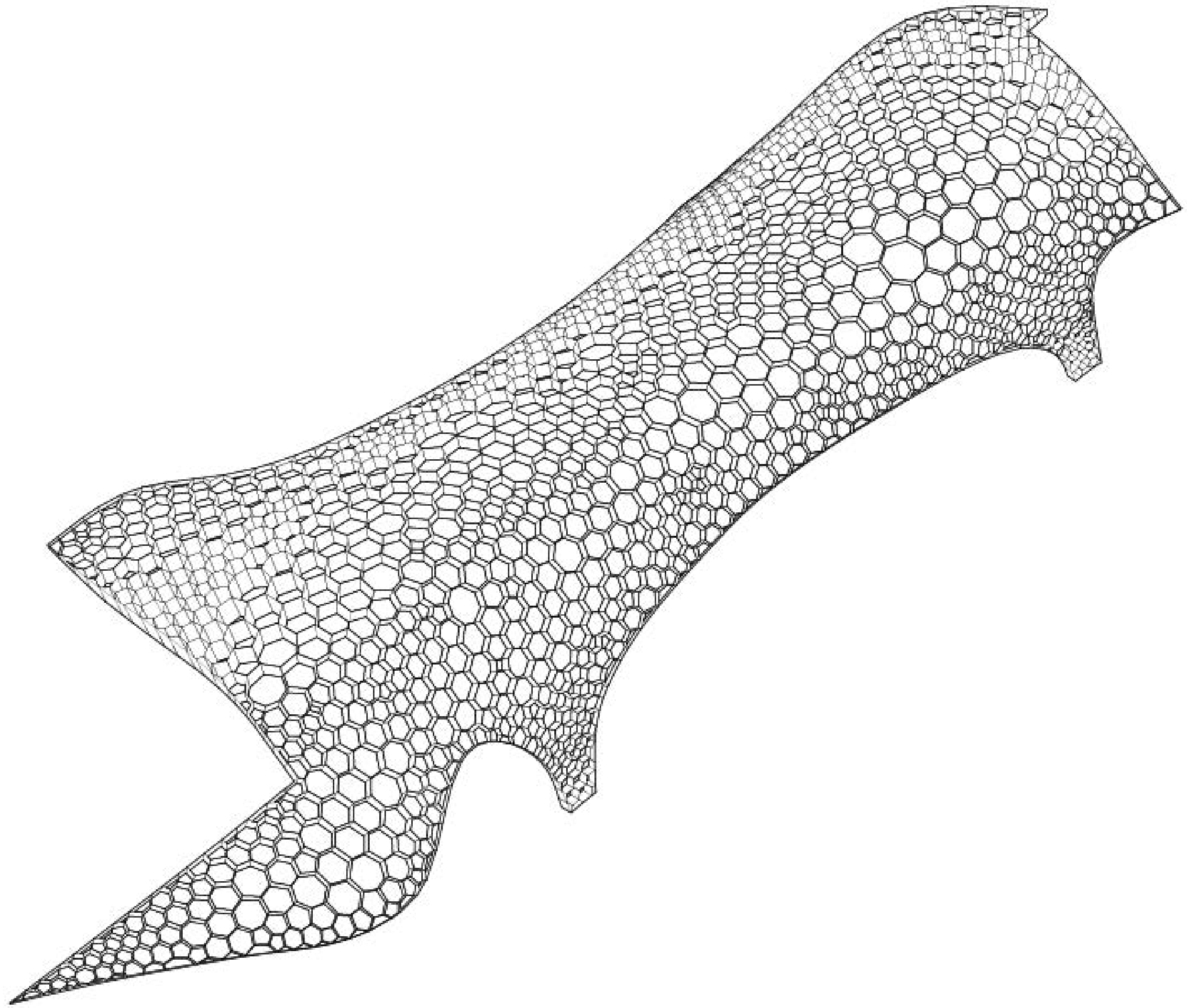
STRUCTURAL VOXELS

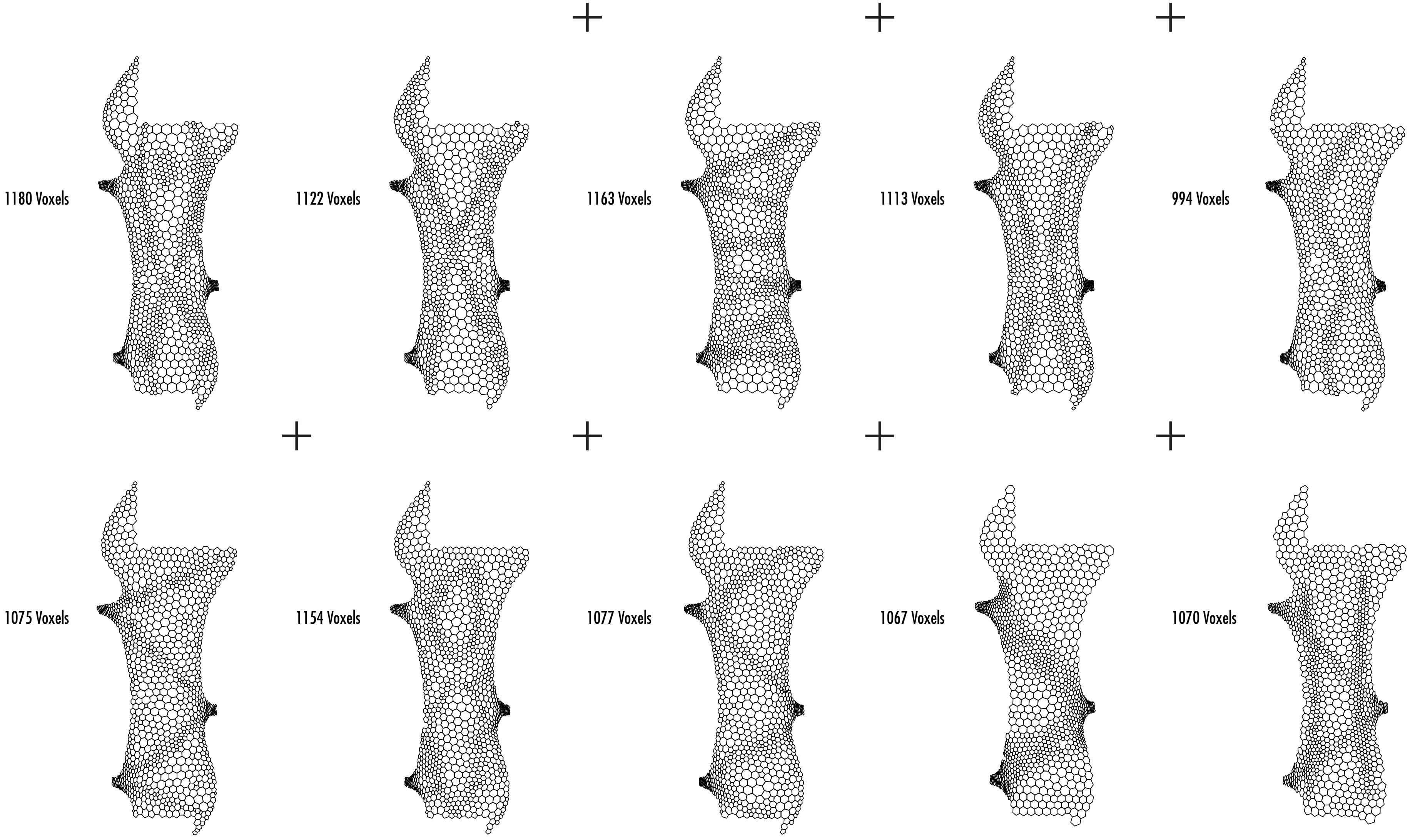
Having a developed a pathway for design input via the PGC, the design development of the structural voxels evolved.

The term voxel was adopted for the concept of a volumetric pixel. It is a three dimensional structural unit which nests together to create a continuous structural shape (think igloo on crack). For this project the voxel was an attempt to use our ability to control the data set in order to inexpensively develop a structural shell.

We had considered making the shell in a more monolithic manner - using either field constructed plywood shell such as a fuselage. We also were interested in using basic boat building techniques to make an epoxy resin and fiberglass (or carbon fiber shell). Both means of construction had longer lead times and a larger duration of on site work.

With the Voxel concept of construction, the geometry of the shell is captured in each individual unit (voxel) so that when assembled the shape emerges. To us this is the moment of "embodied intelligence", where the voxel is derived as an intelligent part. With each voxel holding a place in the shell and a known relationship with its neighbors (which can be indexed and mapped), the order of ***construction operations is no longer held to a linear timeline***.

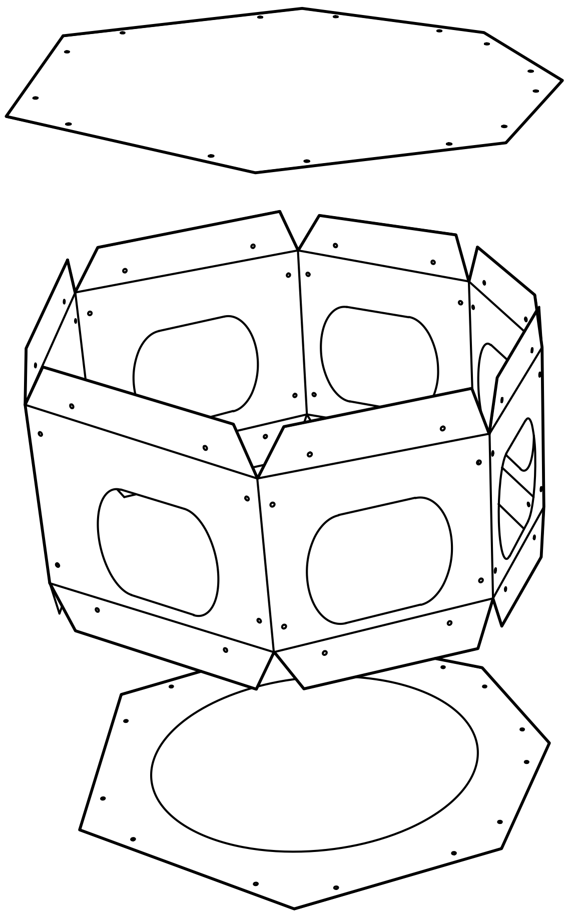




Since the Design Surface is a relatively fixed surface area – the density of the polygons is also established via an interpretation of ranges of sizes, overall polygon count, and number of sides to each polygon.

- Early studies were ranging between 460 polygons packed to 1200 polygons.
- Size limits were developed by speculating the overall weight per “structural unit”
- *Beam* lengths for the faces of each polygon were to be held under 3 ft.
- Visual density played a role as well in determining overall count goals
- The fabrication time and cutting costs were also interpolated into the setting counts
- There were also inputs as to the range of the number of polygon sides

STRUCTURAL VOXEL PARAMETERS



TOP PLATE
VARYING MATERIALS

a. Independent top allows variable gauge thickness for mapping structural performance & cost of production / material

b. Each top plate is drilled or laser cut with the hole pattern which relates to the folded tabs of the rolled section assisting in the cost, ease and precision of the fabrication

c. Tops would be indexed with related voxel neighbors information for a built in assembly map, this is not only good sense for coordination – it also directly reduces cost by shifting the "nature" of the crew required to assemble the sets into shards using a riveter.

SIDE WALLS
16GA STAINLESS STEEL

a. The primary geometric element of the voxel – is developed to share planer faces with each of its neighbors – thus the pyramidal shape of each voxel.

b. Each web section has a face to face relationship that required a rationalization of the geometry in order to be certain the faceting of the polygon faces on the design surfaces would be compensated for in the tapered faces.

c. Each web section has a variable depth – the depth is influenced by:

i. Structural performance

ii. Air passage (sections of the voxels are used as the primary ductwork for the delivery of conditioned air) the sidewalls have knockouts which are based on a developed airflow performance.

iii. Interface with architectural systems, glazing, hvac, trim conditions, and structural systems.

d. Each sidewall is indexed for coordination with neighboring units.

e. Each sidewall would be cut or drilled for the voxel to voxel connections – this is key to the preservation of the shell shape overall and retain a "known" faceting of the shell (this is important in the development of the insulation on the outside of the shell, the step where the design surface wants to be reestablished. Compensation for faceting.)

f. Each web section also had cut into its flattened profile – all of the necessary tabs which would provide attachment points for the top and bottom plates. These tabs were also predrilled to coordinate with the holes in the top and bottom plate – acting as a geometry check as well as a fastener.

BOTTOM PLATE
VARYING MATERIALS

a. Used as an edge and angle guide for the roll up operation

b. Independent bottom plate allows variable gauge thickness for mapping better structural performance more granularly

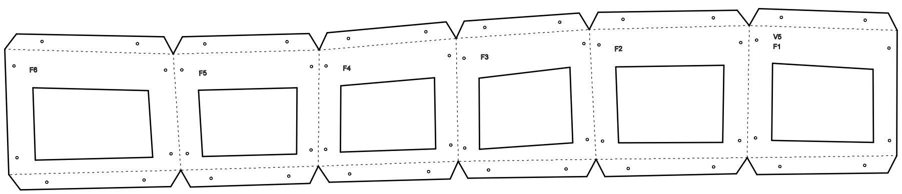
c. Bottom plate was designed to have a large hole in the middle of the plate – this allowed for post assembly work to be done in the proper sequence.

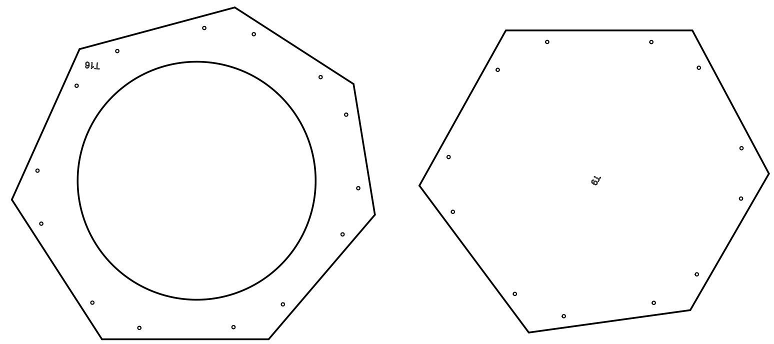
d. The bottom plate hole played a role in the development of the visual voxel system set. It was understood that the profile of the hole edge was liberated to perform as a secondary geometry reference.

e. The flange area varied according to the voxel size and also in relation to the overall structural analysis.

In all, the job requires about 300 sheets of 60” x 120” sheet metal. About 200 of these at 16GA and 100 are 12GA. These figures are rough, and bound to change slightly before the final order.

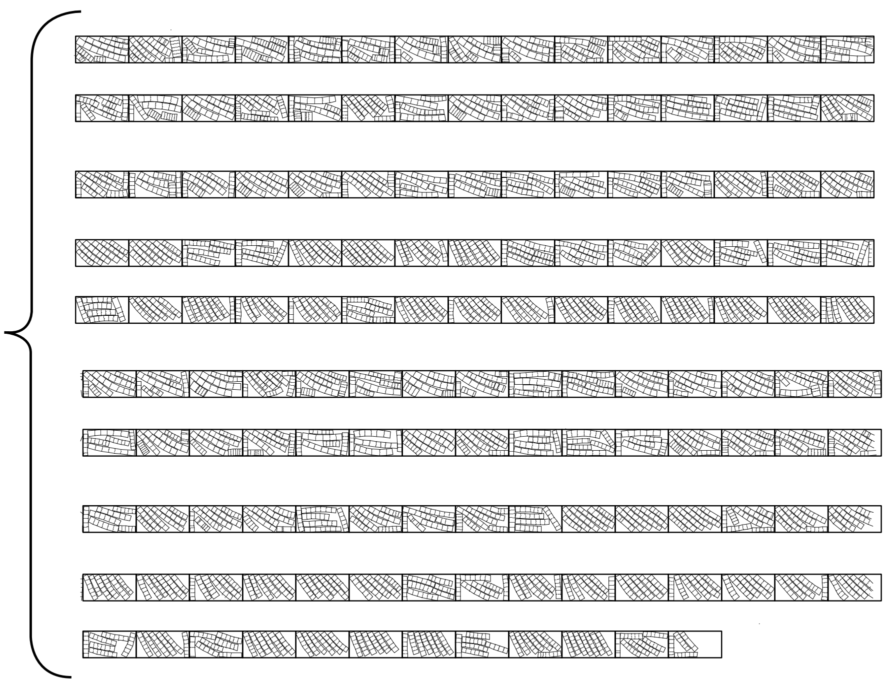
The linear amount of laser cutting is about 400,000 inches. This includes dashed cuts along the edges to assist bending, and the cutting of all rivet holds.





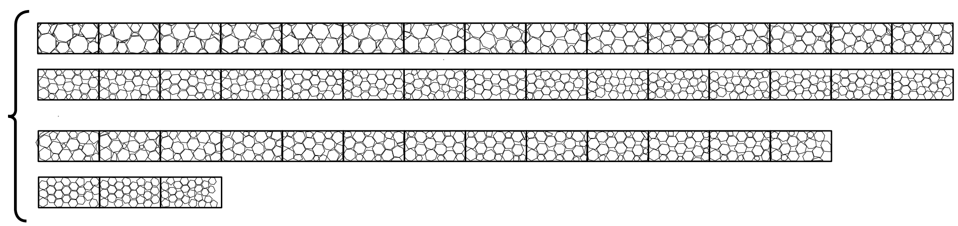
16 GA SIDEWALLS

~200 Seets Stainless Steel



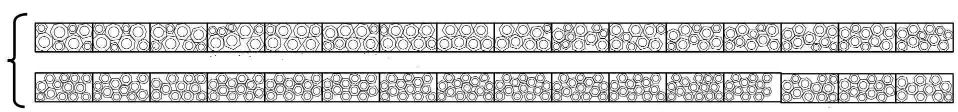
12 GA TOP PLATES

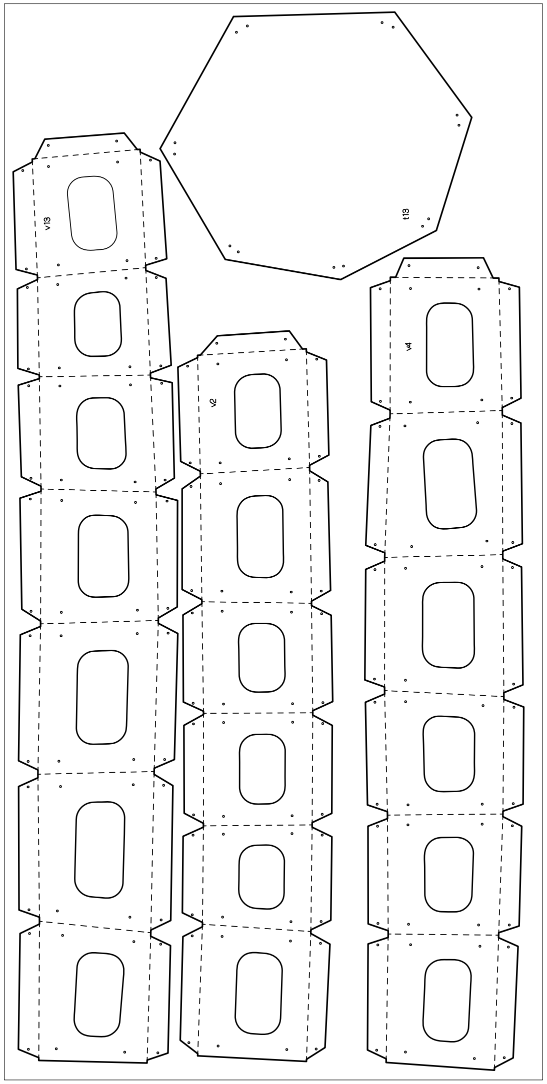
~50 Seets Stainless Steel



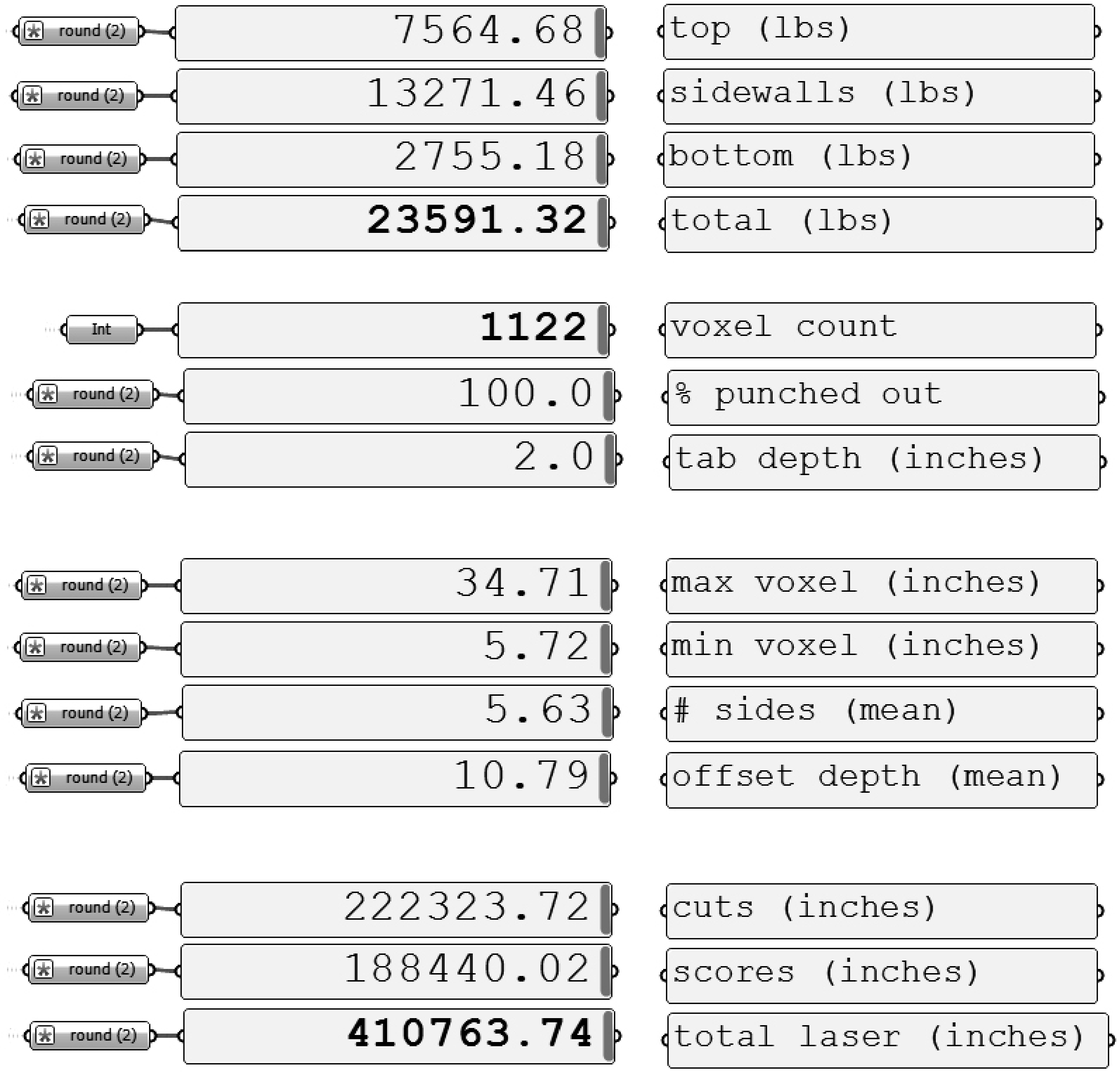
12 GA BOTTOM PLATES

~50 Seets Stainless Steel



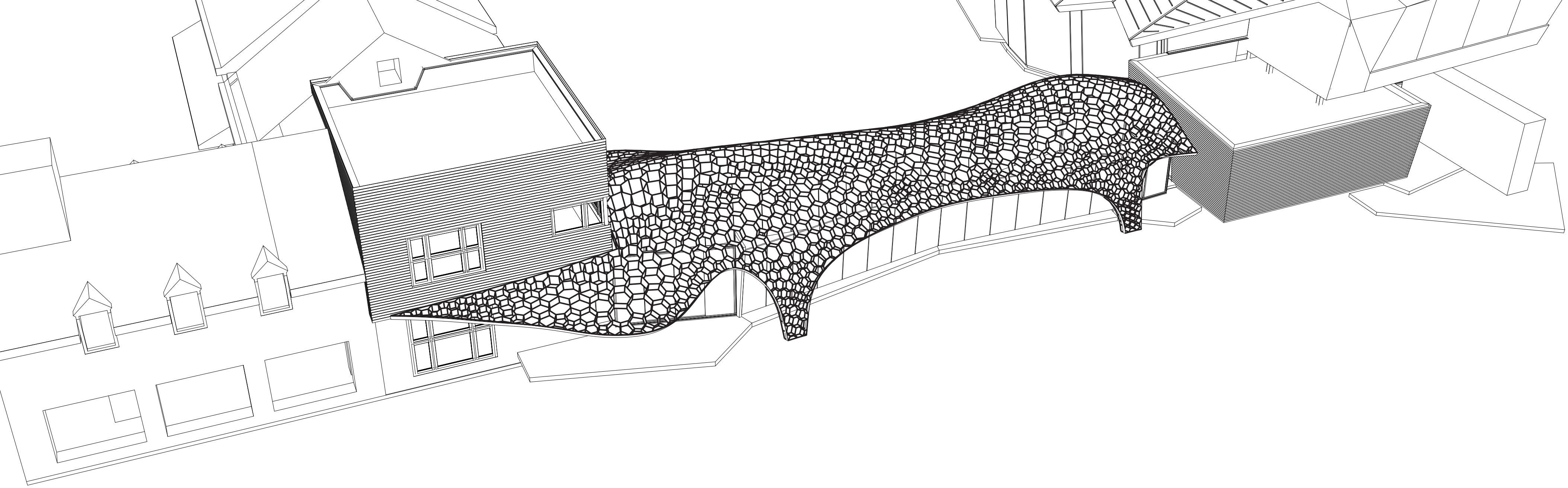


TYPICAL FLAT SHEET
Showing nesting of three unrolled sidewalls and one top cap.



WEIGHT AND MATERIAL MANAGEMENT SHEET
Note sizes of MAX, MIN, and AVERAGE voxels.
Average voxel is about 18” and weights about 22 lbs.

MATERIAL EFFICIENCY READOUTS



STRUCTURAL VOXEL SUMMARY

issued: 9/30/2014

Information for Quantification Purposes Only. Not for Construction/Purchasing

VOXEL	Summary Totals	1107	4474.641	1682.064	1591.777
voxel type	name/description	voxel count	web area (FT2)	top plate area (FT2)	bottom plate area (FT2)
S01	Exterior voxel, typ.	365	1418.423	459.905	444.996
S02	Interior voxel, typ.	205	1118.219	672.128	622.056
S03	voxel at glazing	133	620.048	218.591	207.377
S04	Exterior edge voxel, typ.	187	371.164	61.393	60.902
S05	Exterior edge, strcutural	76	283.248	47.552	48.003
S06	Interior MEP voxel	132	600.800	212.685	200.144
S07	Interior voxel at soffit	0	0.000	0.000	0.000
S08	Interior edge voxel, structural	9	62.738	9.809	8.299
S09	Exterior Edge	0	0.000	0.000	0.000

Seals + Gaskets

Part Number	name/description	part count	part length (FT)	part volume (FT3)
SG02	Weatherproofing Silicone (Dow 791)		27196.021	

Hardware

Part Number	name/description	part count
F01	sidewall fastener	13140
F02	top plate fastener	4380
F303	bottom plate faster	4380

Steel Sheets

Part Number	name/description	part count	part length (M)	part area (FT2)	Weight (LB)
S50	gauge 12 steel sheet	12		597.877 *	
S51	gauge 16 steel sheet	37		1843.950 *	
S52	gauge XX steel sheet	12		578.495 *	

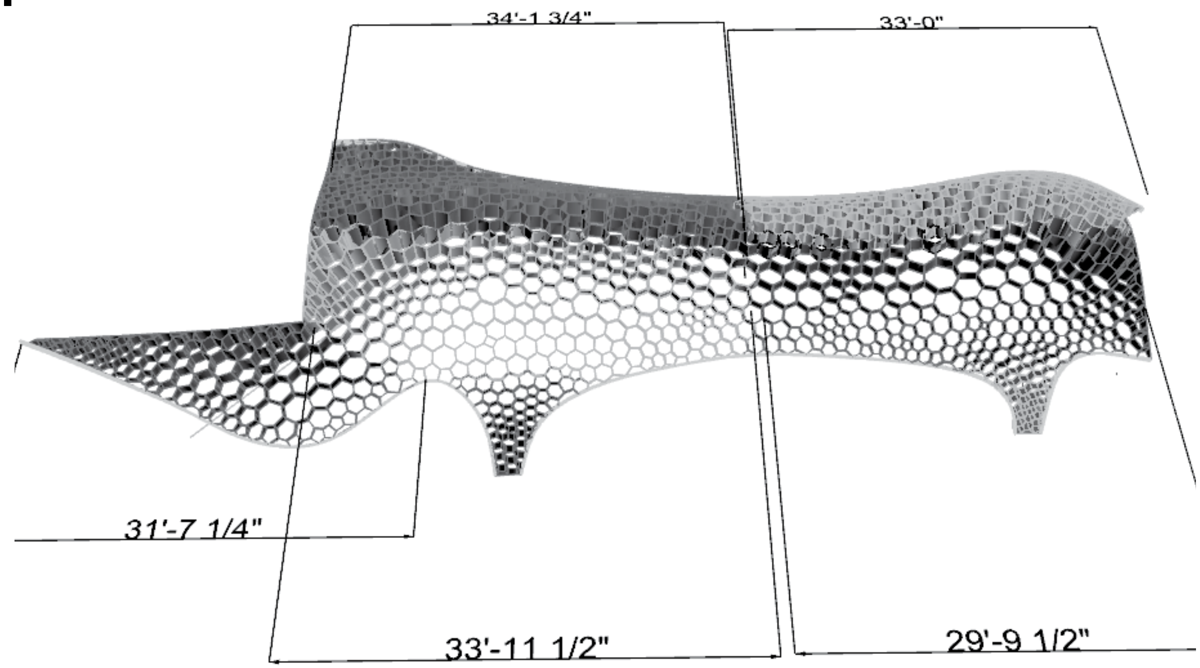
*aproximate sheet area based on 30% waste yield

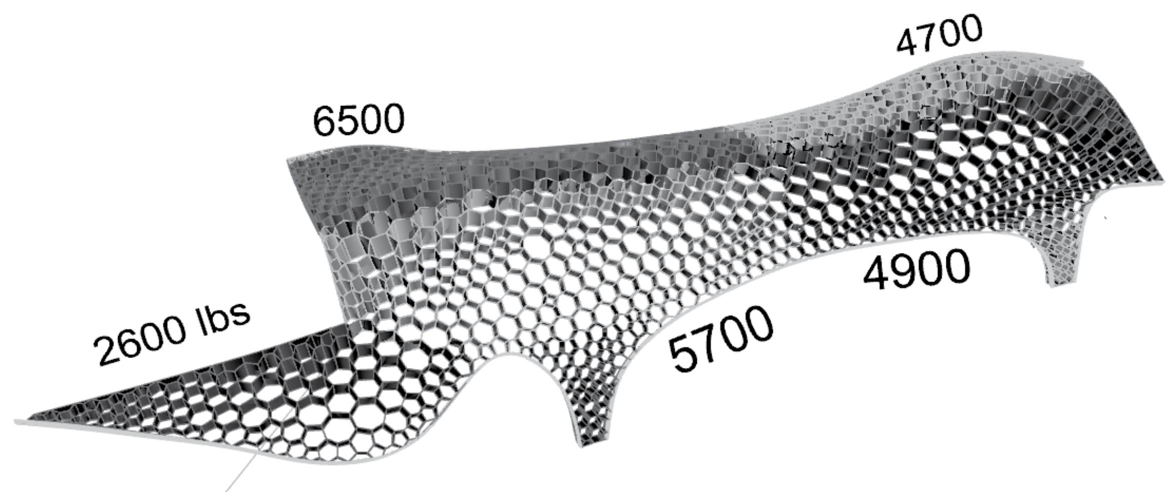
**** hardware + steel sheets counts only reflect S01 counts. Paramaterization of additional typologies under development**

CONSTRUCTION LOGISTICS + BUILDABILITY

Each voxel could in theory be made in the same day in many different places and then converge upon the site to be assembled into a shell. With our goal of limiting site time we knew the voxels could also be aggregated into larger pieces in an offsite fabrication space - we refer to these first stage assemblies as “shards”.

The shards can be any size but for the purposes of this project we were looking to limit the shards to a size manageable by hand with four people. Thus our earliest work was to establish an intuitive understanding of voxel size ranges and sheet metal gauge weights in order to extrapolate loose guidelines for assumptions regarding the overall composition of the shell. This influenced early packing assumptions and mapping influences into the packing of the surface.



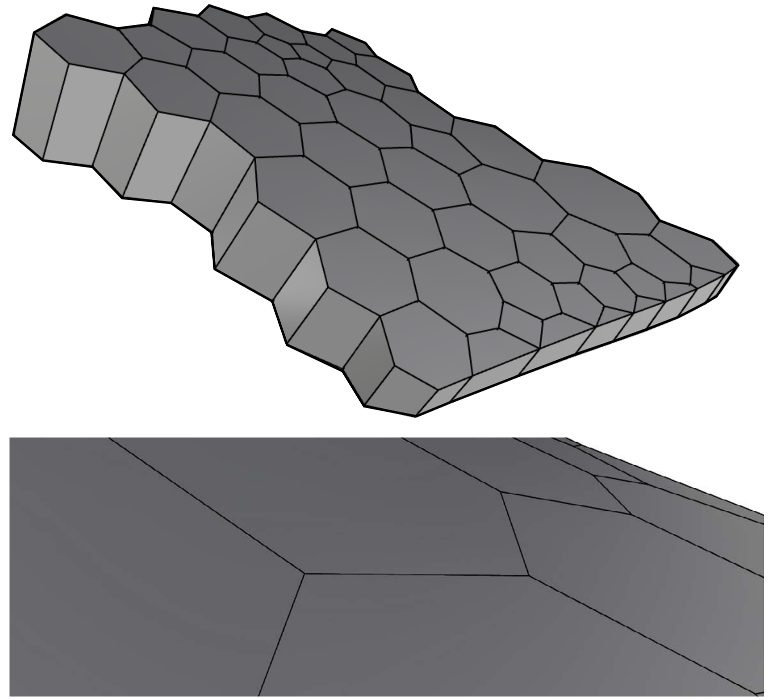


RATIONALIZATION

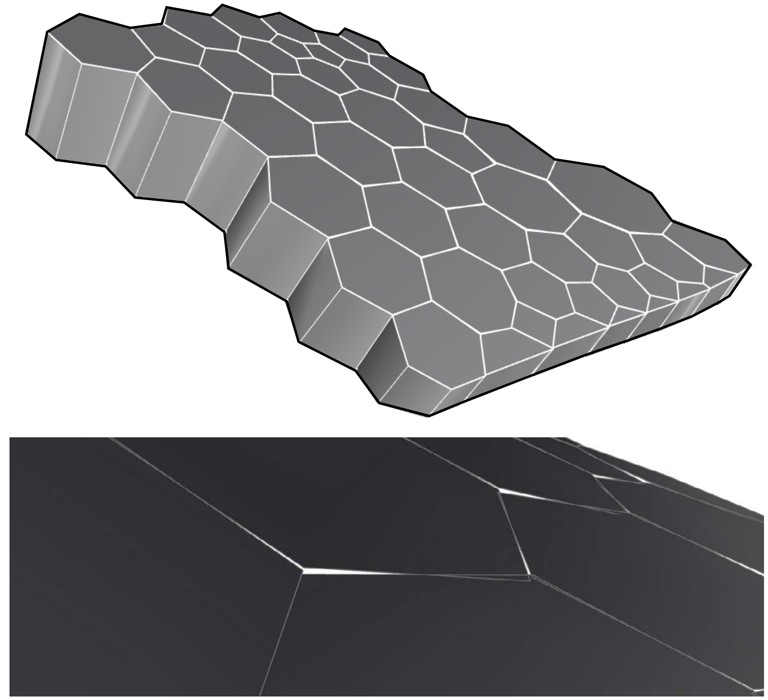
The basic premise of the voxel geometry was to link the top surface (TSV) to the design surface and allow the sidewalls of the voxels to extrude from the polygon shapes developed in the packing/ mapping exercise using the PGC.

The bottom of structural voxel (BSV) is based upon a secondary design surface. That surface has been developed in the context of the variables associated with:

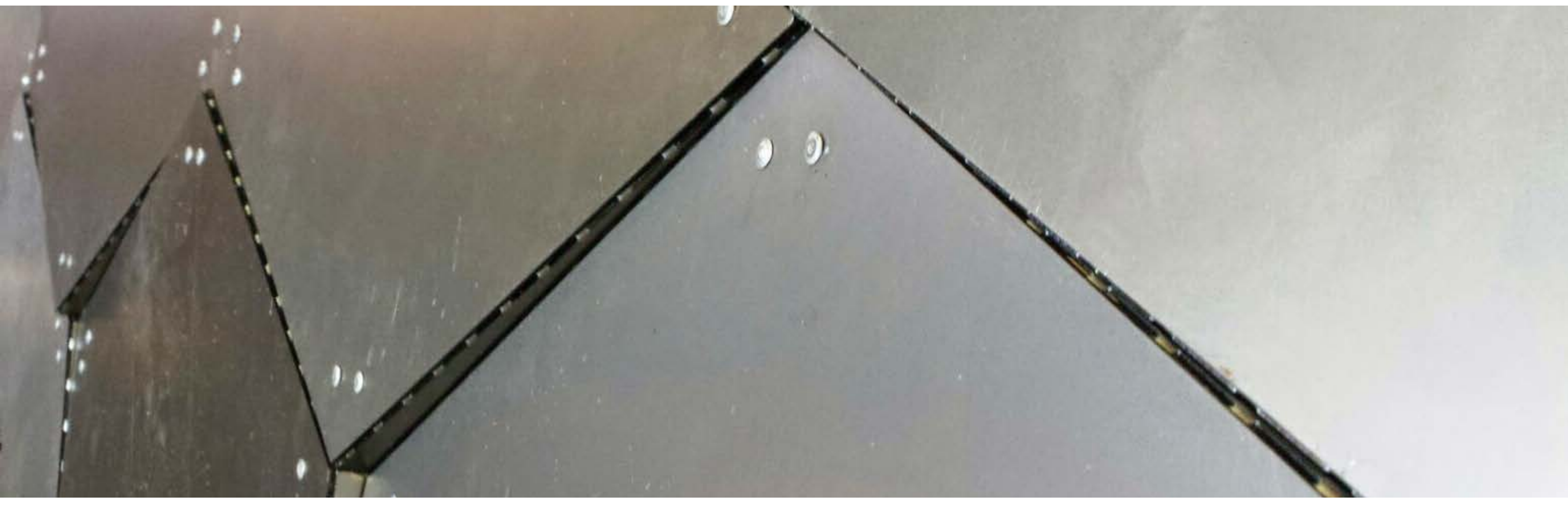
- Structural depth – related to interpreting and linking stress mapping in the shell to the overall depth of voxel.
- The visual appearance of the overall shell geometry
- The walk through experience of individuals in the space.
- Relation to secondary systems such as ductwork (the voxels are to function as the ductwork themselves and therefore have a min effective opening)
- Ability to develop thermal performance through insulation
- The evolution of the visual voxel design work.
- The primary geometry of the polygons is projected onto the secondary design service while being mindful of the taper in relation to the geometry differences and curvature. This is done through an evolved "rationalization process" which insures that adjacent voxels share a clean planer face.



DOUBLY CURVED VOXELS
Pre-Rationalization

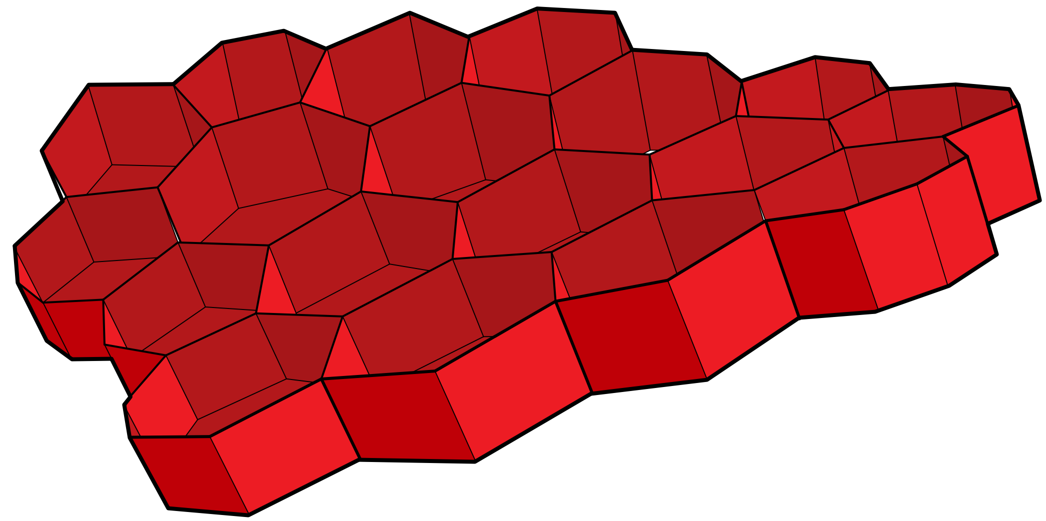


PLANARIZED VOXELS
Rationalized

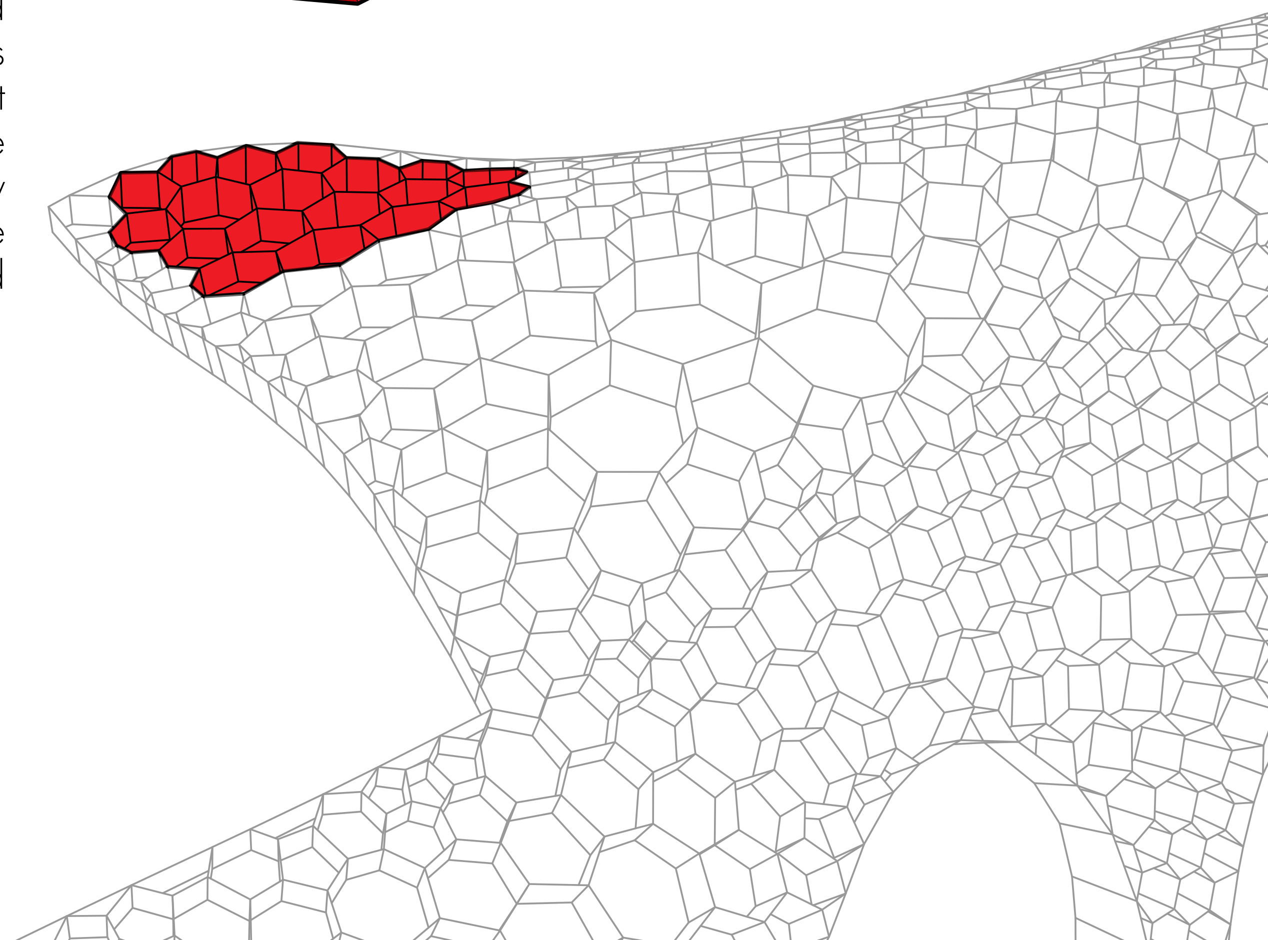


FABRICATION

The material properties of sheet metal have enough variability in physical properties, material type, thickness, simple tooling, weld-ability, etc. without changing the evolving design strategy or the design/fab strategy. We have simultaneously considered multiple gauges of material thickness to relate to overall shell strength (relating to structural analysis models), while relating back to secondary impacts on the process in time and dollars.



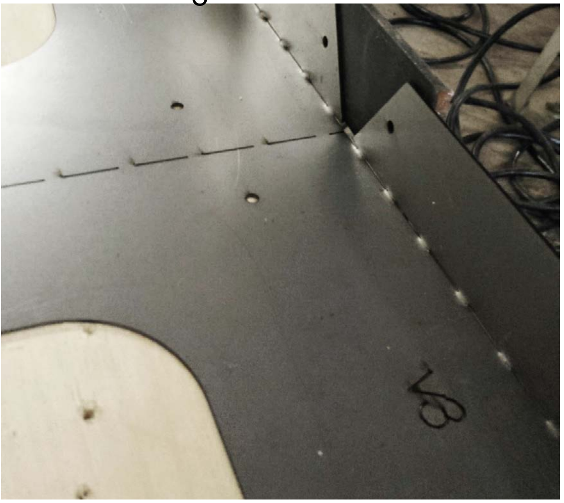
Our second opportunity for utilizing embodied intelligence in the construction/fabrication process was in the consideration of the development of each voxel unit. The design criteria for the sub units of the overall structure were relatively simple: lightweight, strong, inexpensive, flexible as a system, workable by our team so we could maintain the one to one feedback loop.



FABRICATION

SIDE WALLS
ORDER OF OPERATIONS

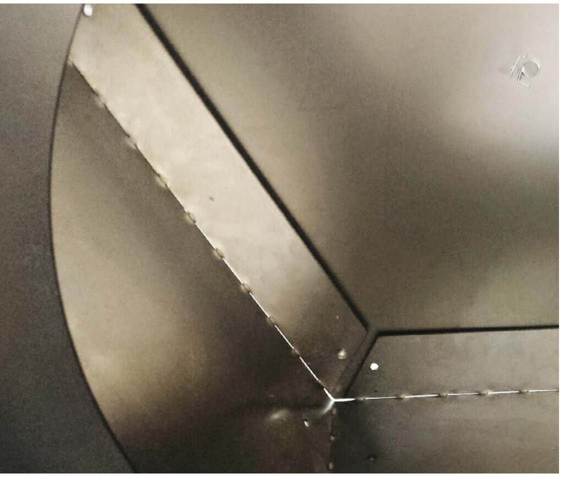
Bending Tabs

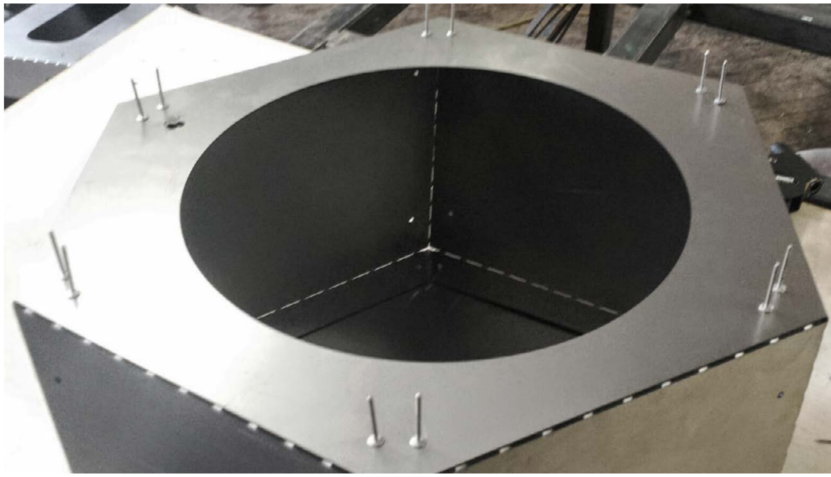


Rolling

Aligning Tabs

TOPS & BOTTOMS
RIVETING





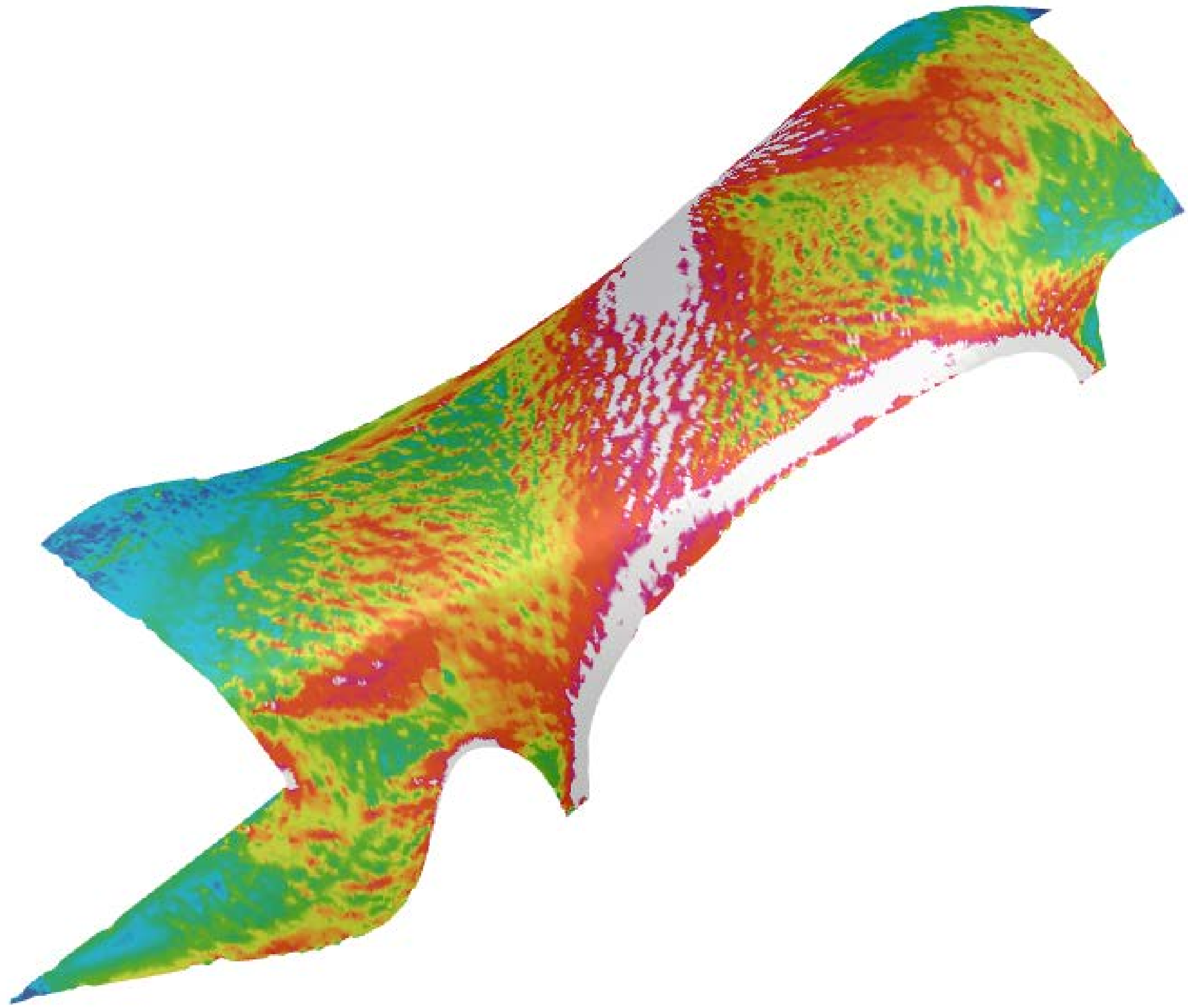
ASSEMBLY

STRUCTURE

Though the structure is a self-supporting shell, it does not act like a true vault. The aesthetic intention for the roof profile is that of a low-sloping curve, thus falling in the domain between that of a conventional portal frame and a true arch or vault.

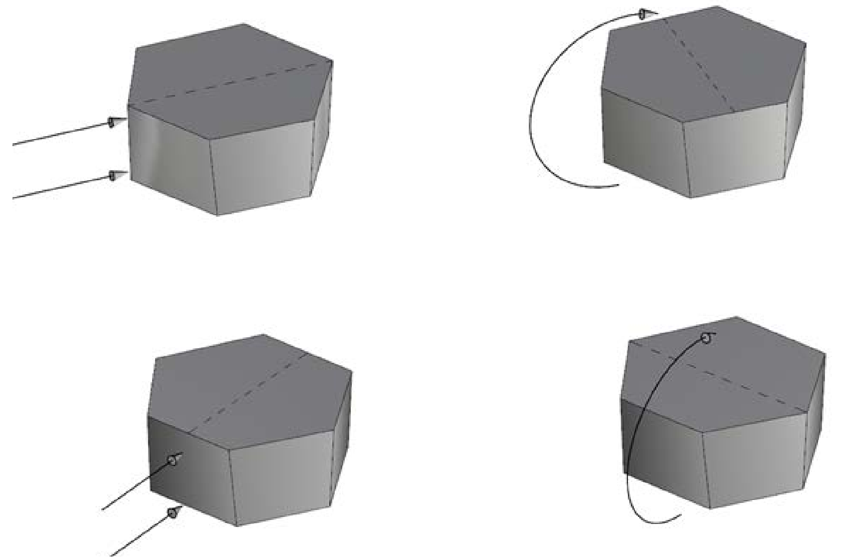
The structural requirements are therefore not universally dictated by compression or flexure, but by the combined interaction of the two. Analytical studies were aimed to resolve the effects of flexure and compression in aggregations of voxels, both at the global and local scale.

In general, flexural resistance is developed via the depth of the shell; the deeper the shell, the greater flexural capacity. A global assessment of the required flexural strength could then allow for the optimization of the shell thickness. Compression failure occurs via buckling of the voxels, which is related to the voxel diameter, another parameter than can be optimized. In summary: flexure is controlled by depth, compression by voxel diameter. The studies described herein examine the effect of these loads at many scales, ranging from global analysis to the scale of individual components.



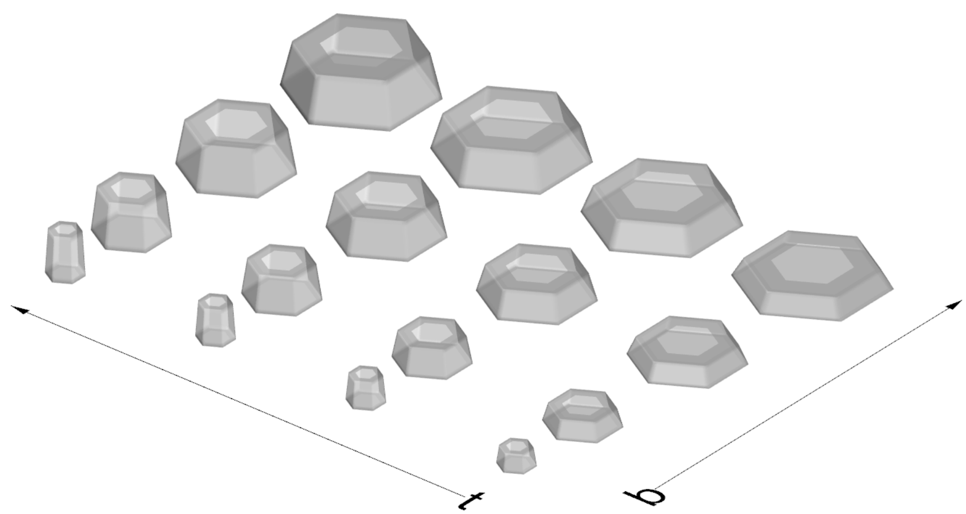
The engineering of the structure is executed with a rules-based approach, such that the design input can be altered and the engineering output regenerated with minimal overhead. By implementing a rules-based approach throughout the various stages of the workflow, each stage can be developed independently without breaking the chain of information. This allows multiple parties to engage and own varying portions of the project workflow, while maintaining a consistent informational framework. Ultimately, design, engineering, and fabrication can then progress simultaneously and in parallel, thereby compressing the overall project timeline.

Structural Consultant



1) Compression at corner
3) Compression perpendiular to face

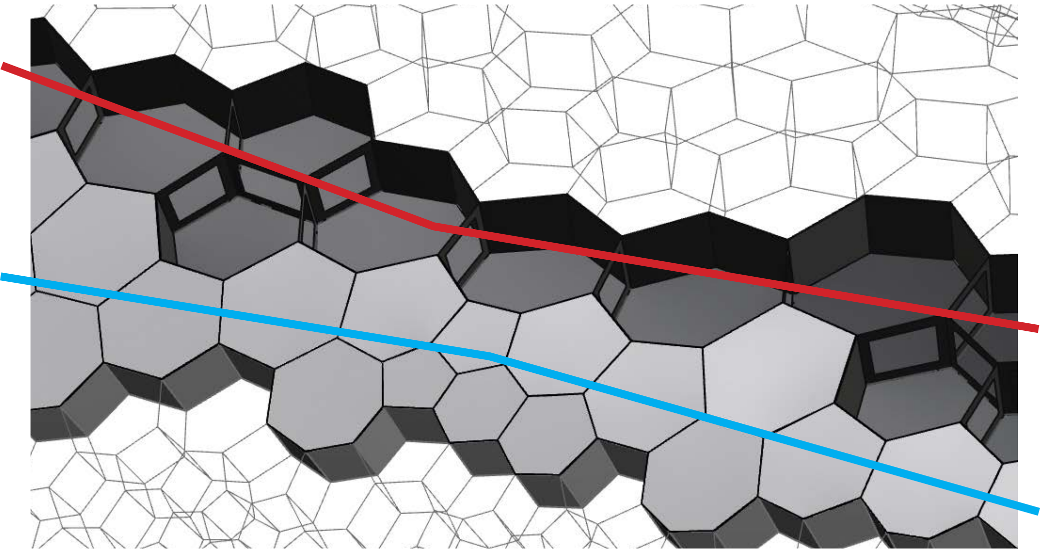
2) Bending at corner
3) Bending perpendicular to face

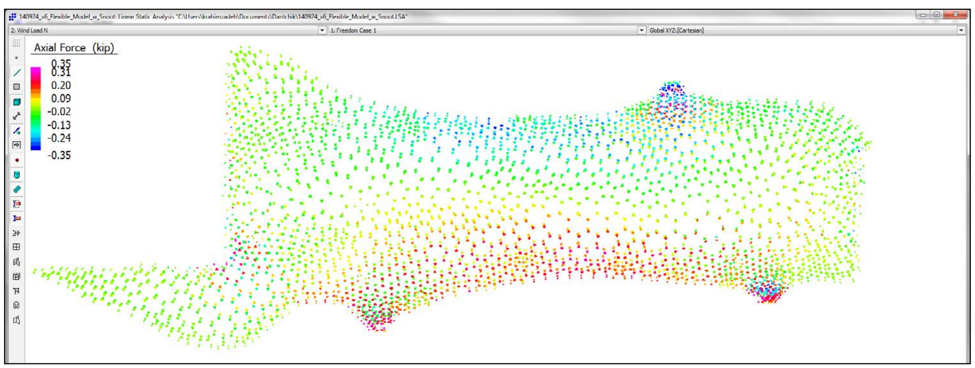


Parametrically Generated Voxels of Varying Aspect Ratio

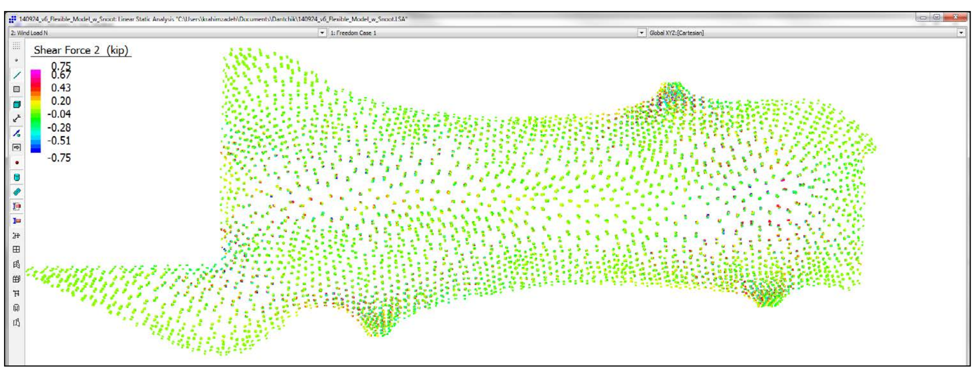

Site + Slab
gineering
inage per Roof Watershedding
Site Access + Staging Strategy
Temporary Construction/Shoring Design
Framing (Snoot + Portal Framing)
Design + Engineering
Tender
Fabrication
packed + shipped
Structural Voxels
Design + Engineering
Prototyping
Fab Documentation
Fabrication Flats
shipping to assembler
Off Site Assembly
assembling voxels
aggregating shards
shards to shells
packing shells for shipment
Insulation
Design + Engineering
Tender
shipping to offsite facility
Fabrication + Fixing to Struct. Voxels
Weatherproofing
Design + Engineering
Tender
shipping to site
weatherproofing shells
Cladding System
Design + Engineering
Tender
Fab Documentation
Fabrication
Shipping Rainscreen to
Integrated Systems
Design + Engineering
Tender
Visual Voxels
Design + Engineering
Fabrication
Site + Slab
Snoot Footings
structural slab
finish slab
demobilization

TIMELINE





Explicit modeling of bolts allows for extraction of bolt forces between adjacent voxels under a directional wind load



Similarly, the bolt shear forces between voxel tabs and caps under a directional wind load

01.

We drastically reduced the number of absolute, independent parts in the building. This allowed us to talk clearly about changes that needed to be made. After that, we had amazing freedom to experiment with geometry, construction logics, and formal effects of the dependent parts of the building. By keeping certain pieces simple, we were able to let the downstream pieces run wild to complex effects.

02.

We were likewise able to design the mechanical systems through our own BIM engine, with advice for general parameters and paradigms from our consultants. This kept the billable hours with MEP consultants to a minimum, while increasing the value (and fun) of the time we did spent with them.

03.

We were able to work with our collaborators and consultants on sets of deliverables that supported a range of architectural solutions–rather than singular, terminal, engineered answers. We were able to glean intuitive data from Front Inc that allowed us to take specific steps forward ourselves, without the expertise that Front has.

04.

Along those lines, we were able to liberate the idea of tolerances, alleviating fabricators, suppliers, and builders from the assumed risk of conforming tightly to our highly complex set of parts. We went from fabricators expecting a hundredth of an inch, to us giving them a foot. This was perhaps our strongest tool in pulling down cost at several stages of the project.

05.

We were able to build and keep design at the same time, so that metal parts were coming off the line while other conditions were still being finished in the model—and all the while we could make design changes that would instantly be updated and reflected in the process of making parts downstream. This let us collapse several timelines into one. The Dantchik Bridge went from sketch in Rhino, to ready-to-build in just over two months.

thank you!