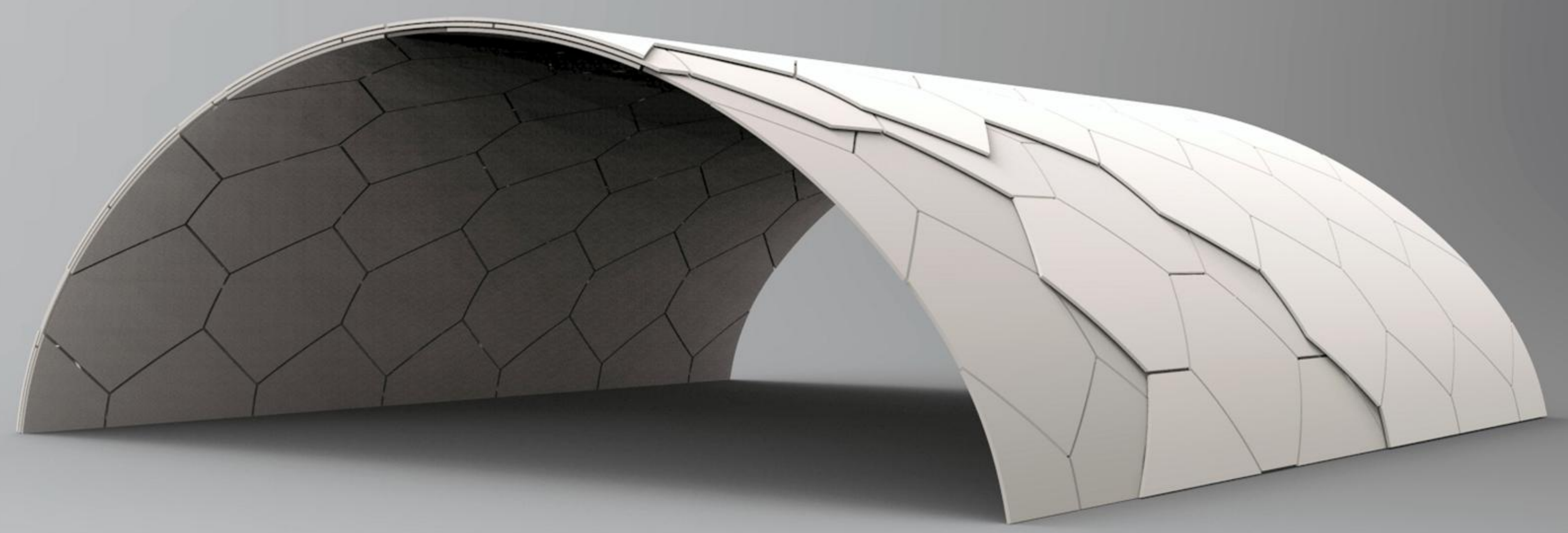
Adrian de Leon | Christopher Laskoski | Marco Martinez

「CAP(c)S」

COMPUTATIONAL ANISOTROPIC PRECAST (CONCRETE) SHELLS

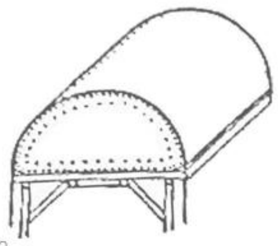


INTRODUCTION:

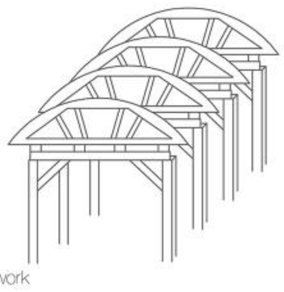
Throughout human history the ubiquitous implementation of shell structures has traditionally incorporated labor intensive and time consuming standards of masonry production and construction resulting in structures with limited geometries, programmatic possibilities, responsive natures, and adaptations. Traditional masonry thin shells are advantageous in that they are capable of long distances using the least amount of materials. However, they suffer from the limitations of standardized materials, the need for reinforcement, geometry, porosity, and a lack of quality control during the construction process. Similar to thin shells, grid shell structures are also able to achieve great spans with minimal material but also allow for more possibilities for porosity. It is limited in that they cannot provide shelter as they are only frames. The internal forces are carried by members and there must follow a restricted path. The overall research objective is to produce adaptive shell structures with diverse, anisotropic performance by optimizing geometries and jointures of tessellated structural modules through a hybridization of thin and grid shell structures. The resulting shell structures will be anisotropic in nature by using the smallest number of molds to produce the greatest variety of customization within the greatest number of precast concrete components.

TRADITIONAL MASONRY VAULTING

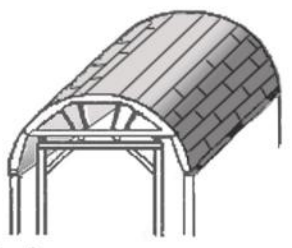
A Vault is an architectural term for an arched form used to provide a space with a ceiling or roof. The simplest kind of vault is the barrel vault (also called a wagon or tunnel vault) which is generally semicircular in shape. The barrel vault is a continuous arch, the length being greater than its diameter. As in building an arch, a temporary support is needed while rings of voussoirs are constructed and the rings placed in position. Until the topmost voussoir, the keystone, is positioned, the vault is not self-supporting.



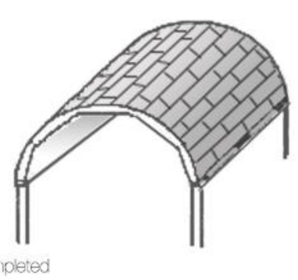
1. Design



2. Formwork



3. Construction



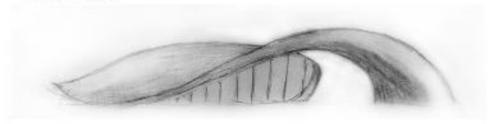
4. Completed

THIN SHELL (ISOTROPIC)

A thin shell is defined as a shell with a thickness which is small compared to its other dimensions, typically at ,minimal1: 200. The load carrying behavior is determined by the geometry of the form, supports, and the nature of the applied load. The structures are capable of spanning large distances with minimal material.

1. Design

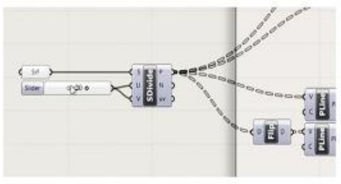
2. Formwork



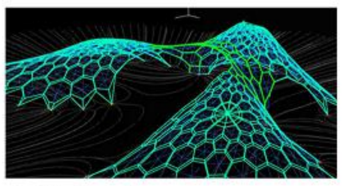
3. Completed

GRID SHELL

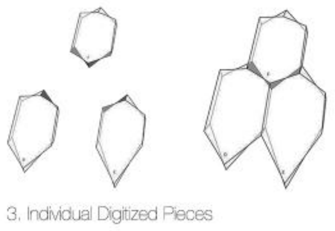
A grid shell is defined as a structure with the shape and strength of a double curvature shell, but made of a grid instead of a solid surface. A long span structure comprised of a network of members creating the single layer grid that forms the curved surface shell. Unlike the thin shell, the loads are carried by members and therefore have to follow a restricted number of paths. Grid shells can be used to reduce the weight of the structure, offer better lighting conditions, or add aesthetics. Grid shells can could be considered both a structure and a facade.



1. Design (Grasshopper)



2. Digital Output

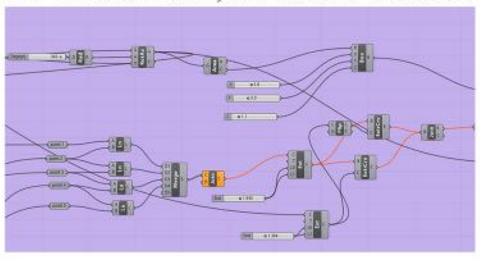


3. Individual Digitized Pieces

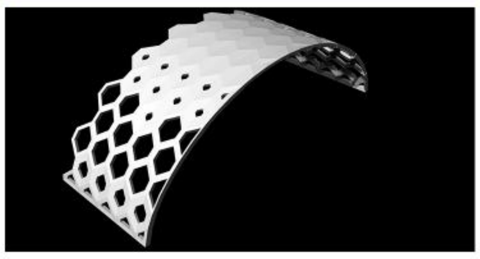
4. Completed

COMPUTATIONAL ANISOTROPIC PRECAST CONCRETE SHELLS

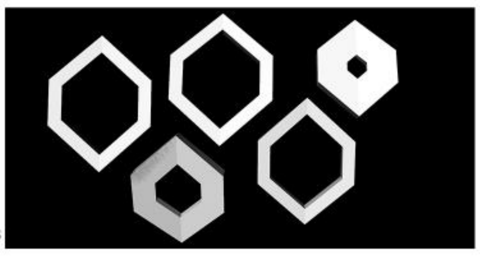
The hybidization of Thin Shell Masonry and Grid Shell structures.



1. Design



2. Digital Output



3. Individual Digitized Pieces

4. Formwork

5. Completed

Adrian de Leon | Christopher Laskoski | Marco Martinez

⌈CAP(c)S⌋

CONTEXTUAL PERFORMANCE:

Stadiums	Building components
Pavilions	Roofs
Churches	Facades
Airports	Exhibition Halls
Industrial Facilities	

PRECEDENTS:

THIN SHELL

Guastavino tile vaulting:
Guastavino tile vaulting relies on the adhesion of two to three layers of overlapping tiles which are woven together with fast setting mortar. This method allows for quick construction, less scaffolding, and saves on materials and cost of construction. The tiles are layered at different orientations, giving the assembly strength. The first layer is set with a quick setting adhesive and the rest of the layers are set with regular mortar. Guastavino tile vaulting can generally be done with little or no formwork.

Casar de Cáseres Bus Station:
The building utilizes concrete as the principal material for all elements of the building. The most distinctive feature of the project is the curve of the concrete folding in on itself as the ground sweeps up to form the walls which then loop back to create the roof. The geometry is was gives its stability. It is not merely just an aesthetic design, but also a functional as it helps to expel exhaust from the buses.

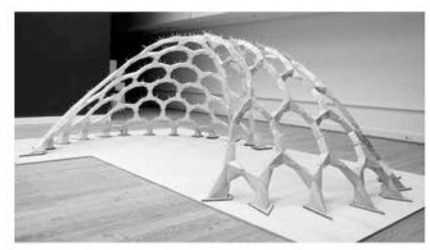
MLK Jr. Park Stone Vault:
Recent developments for the computer controlled fabrication of individual stone blocks of a free form masonry vault in Austin, TX. Based on structural requirements, state of the art, 5 axis, stone cutting processes and software solutions used in the stone industry, new methods were developed to optimize the block geometry and machine strategies for this structure. A customized software program was written to simplify part preparation, reduce machine time and extend known fabrication procedures in a flexible and streamline setup.

GRID SHELL

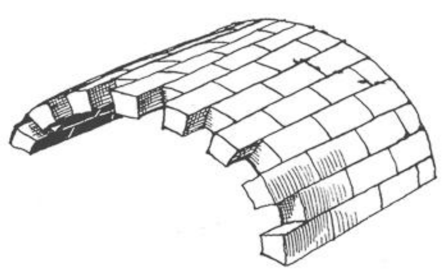
Palazzetto dello Sport:
The dome of the stadium is actually a thin-shell but uses a ribbing system similar to a grid shell structure as the supporting structure. The design was a result of simple geometry and prefabrication methods. Rhomboid hollow flat blocks were prefabricated and were spread out over the ribbed form.

Prevault Pavilion:
The PreVault pavilion is a compression-only precast concrete vault designed and built at 1:1 by a student group in dialogue with engineers as a three week research project. The structure was first assembled in a gallery space at the Aarhus School of Architecture, then demounted and reassembled in less than a day onsite at the Aarhus Festival.

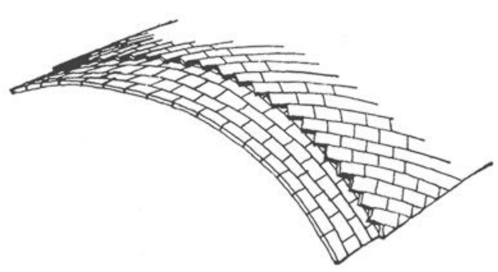
Concrete Gridshell Pavilion:
The form was generated through custom written dynamic relaxation software and fabricated through folded mold techniques and CNC machines. Catenary curves were used in order to counteract gravitational loads. Each individual precast component was unique. They were designed with a number of parametric variables which enabled different variations in the component design. The pieces consisted of concrete that was poured into plastic molds. After each piece was removed and assembled together, they formed a gridshell.



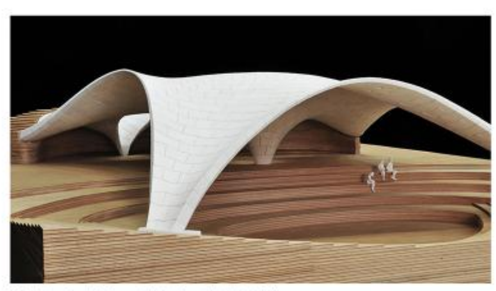
Comparison of the traditional stone vault



a. Traditional stone vault



b. Guastavino tile vault



MLK Jr. Park Stone Vault, Austin, TX, USA
(Block Research Group)

Casar de Cáseres Bus Station, Spain
(Justo Garcia Rubio)

MATERIAL PROPERTIES FOR HYDRO-STONE

Description

Hydrostone is one of the hardest and strongest of all gypsum cements, it is typically recommended for producing high-quality novelty and statuary casting requiring extremely hard surfaces. This product is self-leveling when poured and not suitable for hallow cast applications. Hydrostone must be mechanically mixed for best results and it is a high water absorption resistance material.

COMPOSITION OF INGREDIENTS

MATERIAL	WT%	TVL(mg/m3)	PEL (mg/m3)	CAS NUMBER
Plaster of Paris ($CaSO_4 \bullet ½H_2O$)	>85	10	15(T)/5(R)	26499-65-0
Portland Cement	<10	10	15(T)/5(R)	65997-15-1
Crystalline Silica	<5	0.05(R)	0.1(R)	14808-60-7

Physical Properties

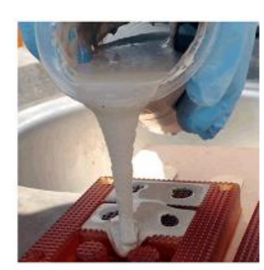
Normal consistency (lbs. water/100 lbs. product)	32
Hand Mix Vicat Set, Target (minutes)	20-30
Compressive Strength, One hour after set (psi)	4,000
Compressive Strength, Dry (psi)	10,000
Density, Wet (lbs./cu. ft.)	119.0
Density, Dry (lbs./cu. ft.)	108.0
% Maximum Expansion	0.24%

Mixing Process

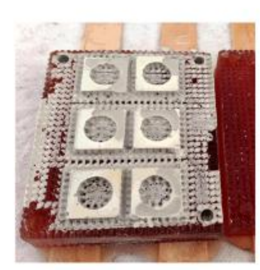
1. Add the plaster to the water

2. Mix the plaster

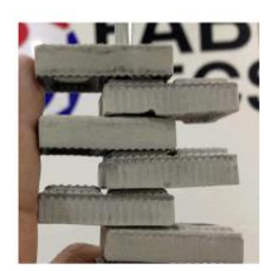
3. Paste must be smooth



4. Add the mix to the mold



5. Let the mix set in the mold



6. The cast are ready to use

Source USG Industrial & Specialty Solutions. www.usg.com/content/dam/USG_arketing_Communications/united_states/

Adrian de Leon | Christopher Laskoski | Marco Martinez

「CAP(c)S」

GRASSHOPPER DEFINITION PROBLEM

COMPARATIVE TILE LAYER ADJACENCIES IN SECTION

Although previous grasshopper definition successfully demonstrate a capacity to produce faceted single layer tile vault it left the following unresolved issues.

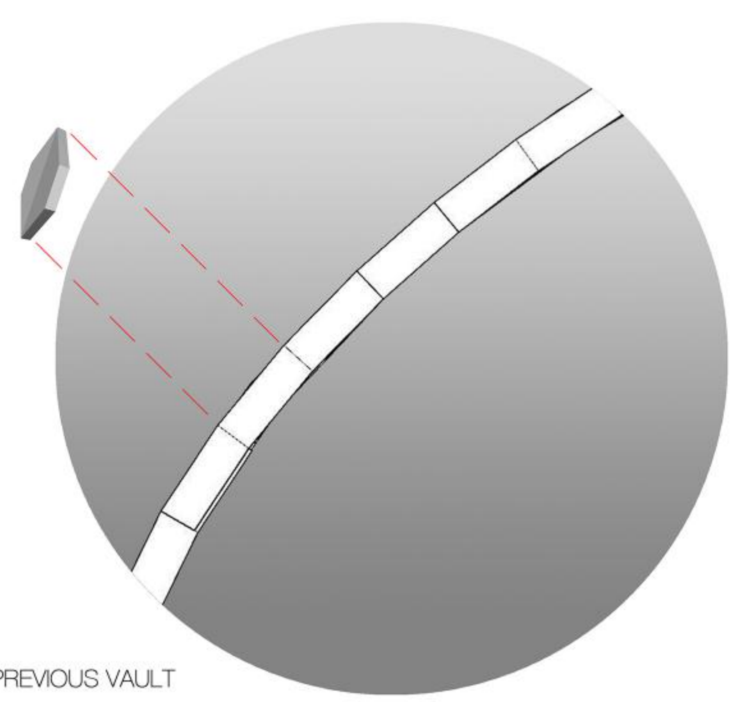
1. MULTIPLE STRUCTURAL LAYERS
2. LAYER ROTATION
3. TILES WITH CURVILINEAR FACES
4. HARMONIC CORRESPONDENCE BETWEEN ADJACENT LAYERS

Universally consistent spacing between all three layers of curvilinear tile geometry applied to a reference surface in the newly created grasshopper definition.

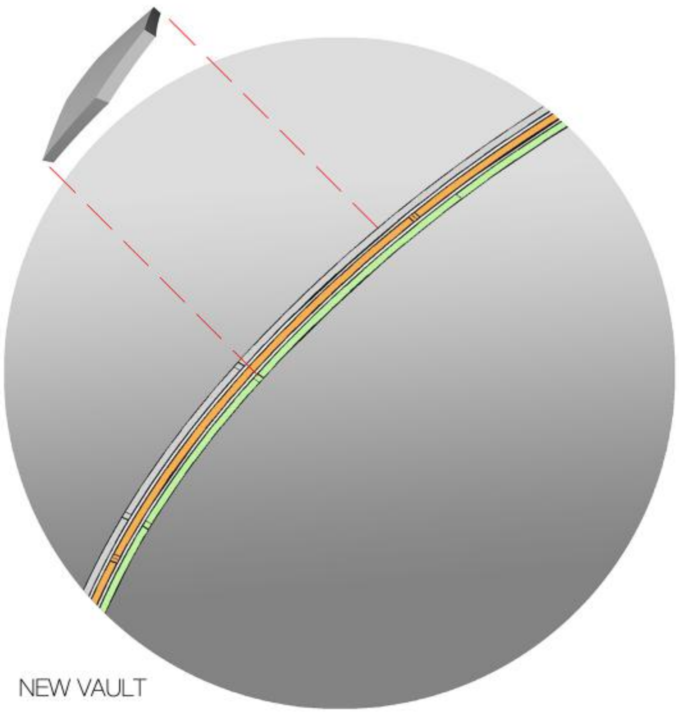
Layers of faceted tile with inconsistent spacing between each other resulting from the first grasshopper definition.

Consistent spacing between all three layers curvilinear tile geometry applied to a reference surface.

LAYERS OF FACETED TILE WITH CONSISTENT SPACING



PREVIOUS VAULT



NEW VAULT

SOLVING FOR THIN SHELL

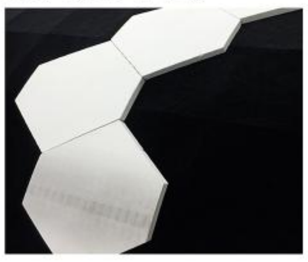
TILE COMPARISON

COPLANAR TILES

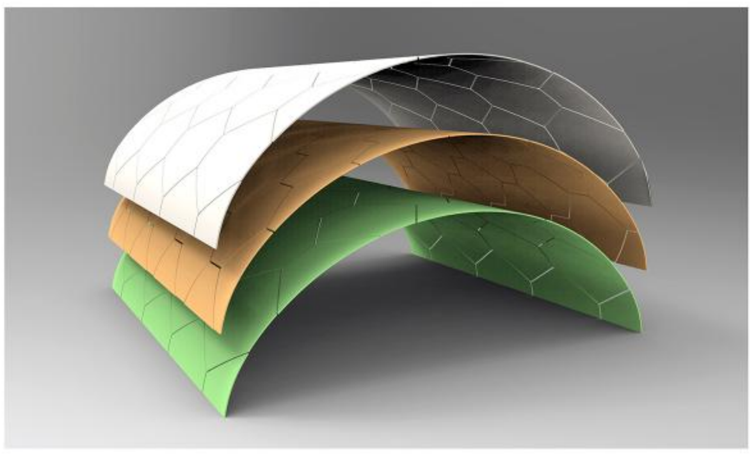
GAP DUE TO THE PLANAR GEOMETRY OF THE ORIGINAL VAULT

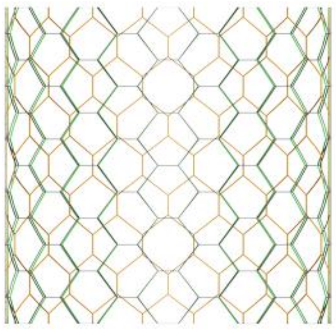
OVERLAPPING OF LAYER ONE AND LAYER TWO

CURVED TILES

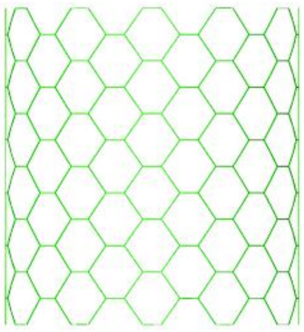


NEW GRASSHOPPER DEFINITION TO INTEGRATE LAYERING AND ROTATION

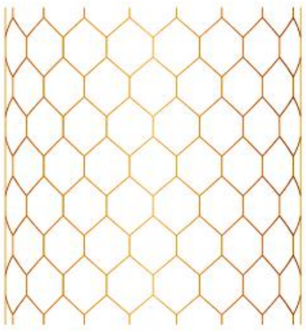




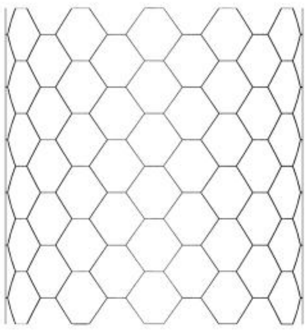
APPLICATION OF THE THREE LAYERS ON THE CYCLOIDAL VAULT



LAYER ONE



LAYER TWO ROTATED AT 30 DEGREE ANGLE



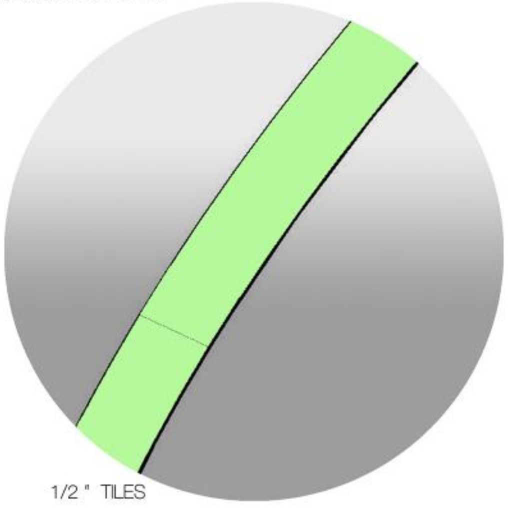
LAYER THREE

LAYER VARIABLES

DETAIL SECTIONS OF THE THREE VAULTS

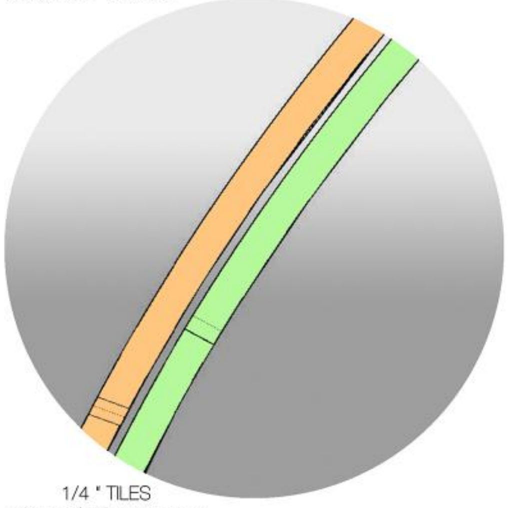
TRADITIONAL VAULT

SINGLE LAYER



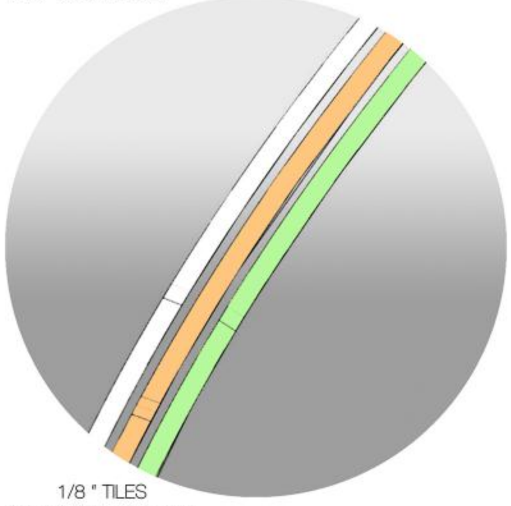
1/2 " TILES

DOUBLE LAYER



1/4 " TILES
with a 1/16" mortar gap

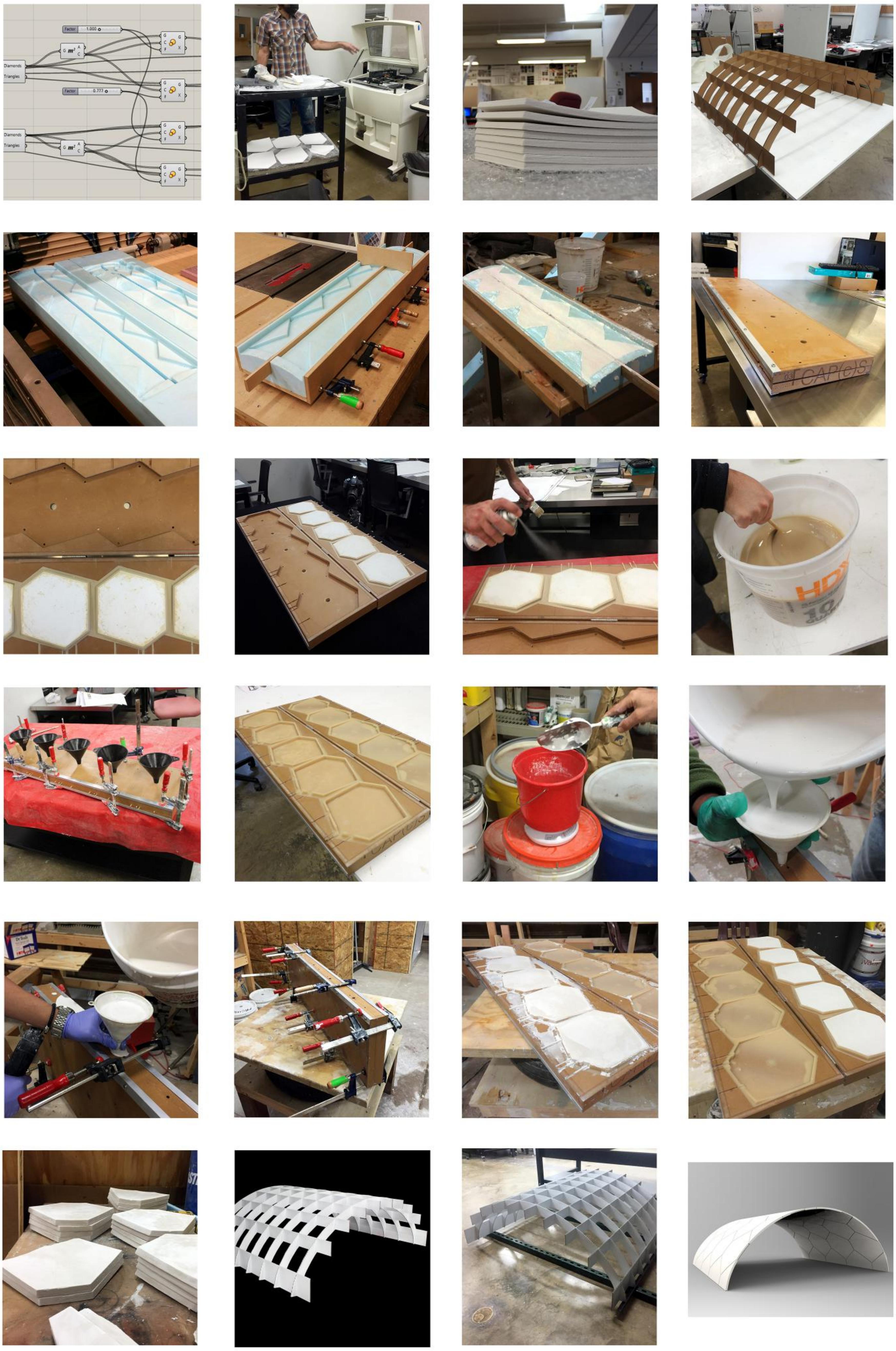
TRIPLE LAYER



1/8 " TILES
with a 1/16" mortar gap

The three layered vault should have a larger compressive strength

FABRICATION PROCESS

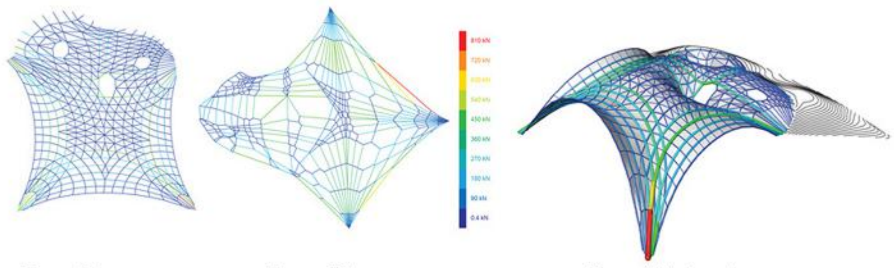


TESTING METHODS

Based on the research by the Polytechnic University of Catalan with collaboration of other research teams in MIT and ETH on the structural analysis of tile vaulting methods and variables specifically the Guastavino vaulting.

A research team attempted to investigate the suitability of the analytical method used and to evaluate the contribution of the selected variables of the stability of the vault and compare the two results.

Philippe Block and John Ochsendorf have developed Thrust Network Analysis (equilibrium analysis method in three dimensions). It is a new methodology for generating compression-only vaulted surfaces and networks which allows designing forms using the minimum compressive material.



Form Diagram Force Diagram Thrust Network

The Catalan Vault

The research aims to quantify the contribution of resistance and or balance of the elements that determine the bearing capacity of the tile vault as shape, span, thickness and the existence of spandrels walls.

Jose Luis Gonzalez, one of the leading specialists in restoration of Catalan vaults recommends load testing as the most reliable method to test its strength.

- Uniform testing results are obtained by the application of sand bags which transfers the load uniformly. The variation in the results can naturally vary depending on the type of mesh or finite element used according to Lopez and Rodriguez in the "Guastavino Vaulting".

Pere Roca, an engineer from Barcelona also recommends limit analysis and macromodelation:

- A precise macromodelation of the geometry has to be made.
- Consider the material nonlinearity
- Consider limited compressive strength
- Possible consideration of tensile non-zero (but very limited)
- Consider geometric nonlinearity

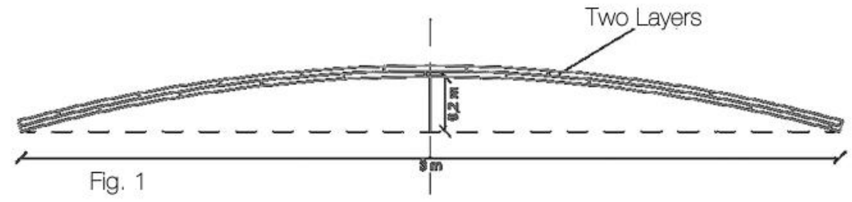


Fig. 1

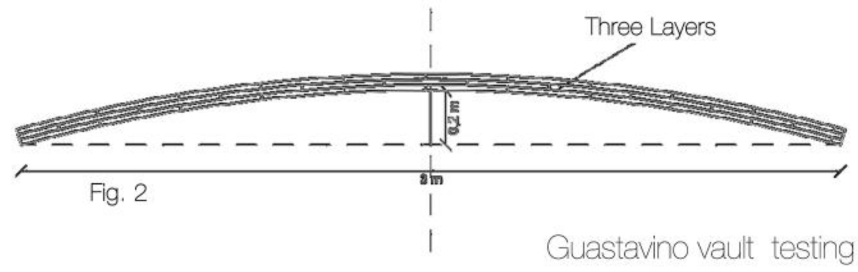


Fig. 2

Guastavino vault testing

INDUSTRY STANDARDS

Some of the most important variables for testing are the uniformed load distribution, eccentric loads and finally the combination of these two. Virtual calculations are compared to model testing through the application of an evenly distributed weight and compared to the software calculations. This type of analysis can provide quantitative information, identifying high compression points or associating tension to cracks or fissures.

The vaults (Fig. 1 & 2) have a span of 9.84ft and a width of 3.28ft. The different parameters are: thickness (2 or 3 layers), the existence of spandrels walls and the height 7.87in or 11.81in.

Load variables:

- Uniform loads
- Eccentric loads
- Uniform + eccentric loads.

Load Testing with Sandbags

TESTING DATA OUTPUT (Cycloidal Vault)

Table 1: Quantity and weight of masonry
Vault surface area
Vault thickness (1-3 layers)
Tile (dimensions; unit weight):
  Quantity
  Weight
Mortar:
  Quantity
  Weight
Total weight of Vault

Table 2: Quantity and weight of formwork
Dimensions (units weight)

Table 3: Estimate of labor for tile laying
Average vault construction crew
Total duration of tile laying
  First layer
  Second layer
  Third Layer
Estimate labor for tile laying
Estimate of labor/sq. meter:

Table 4: Structural load testing
Application of load (sand bags)
  Total weight applied:

TESTING PROCEDURES

Testing for strength based on layering methodology that adheres to the Thin Shell definition (minimum of 1:200)

Dimensions of vault: 4 ft x 4 ft

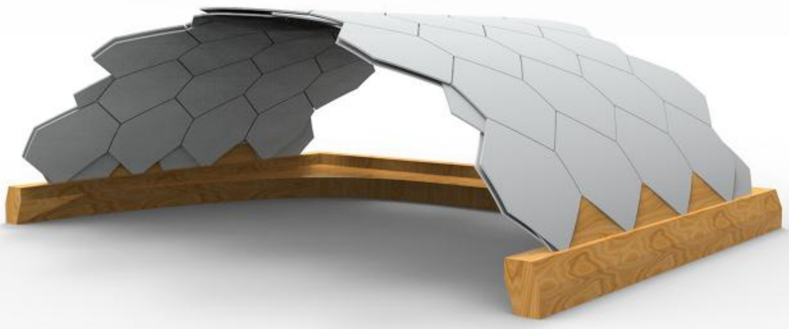
- Variation in Thickness: 1 Layer

- Layering
  Pattern variation

- Different materiality in layering

Structural Load Testing

Vault 1 assembly



Vault 2 assembly

Adrian de Leon | Christopher Laskoski | Marco Martinez

DOME INITIATION AND PROCESS

Research agenda is to investigate and explore using thin shell and grid shell on a different surface geometry such as a dome through computational design. By applying similar techniques as with the cycloidal vaults and with the Guastavino layering system allowing for a solid and porous dome exploration that maintains a higher degree of compressive strength.

STRUCTURAL INTUITIVE DIRECTIVES

Minimize irregularities
Maximize centroid coordination
Maximize layer to layer consistency
Stabilize printing and geometry.

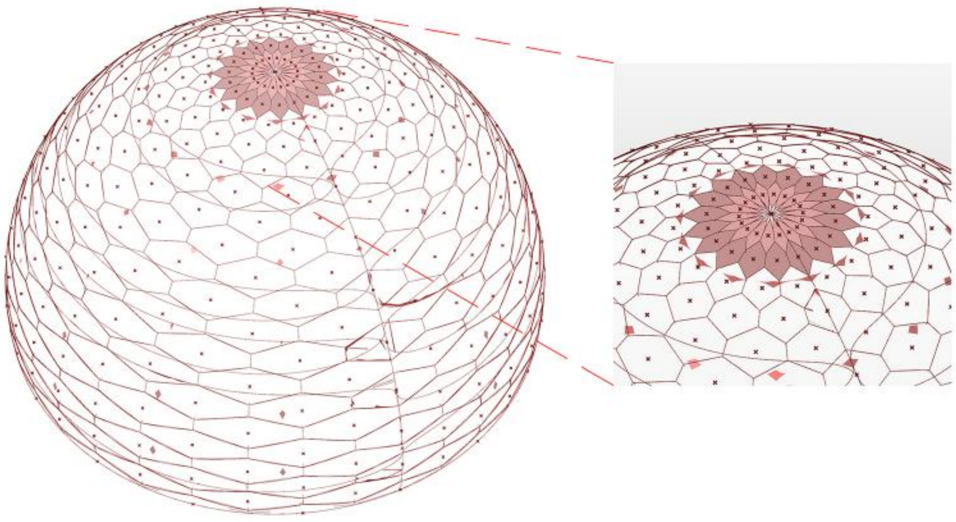
Precedents

NERVI - Palazzo dello Sport

Pantheon

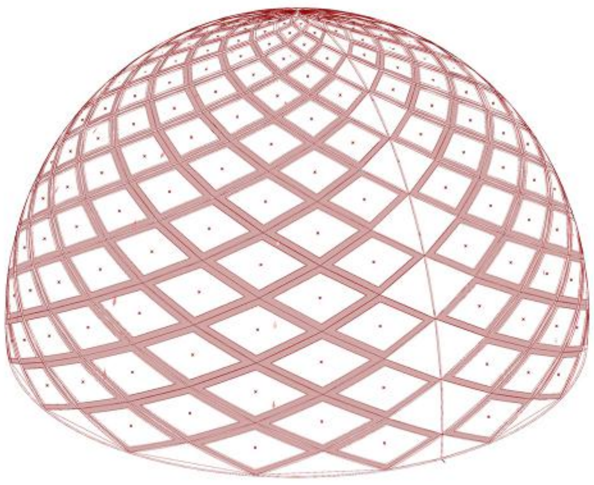
Rafael Guastavino - Brooklyn zoo

OCULUS & SURFACE ISSUES

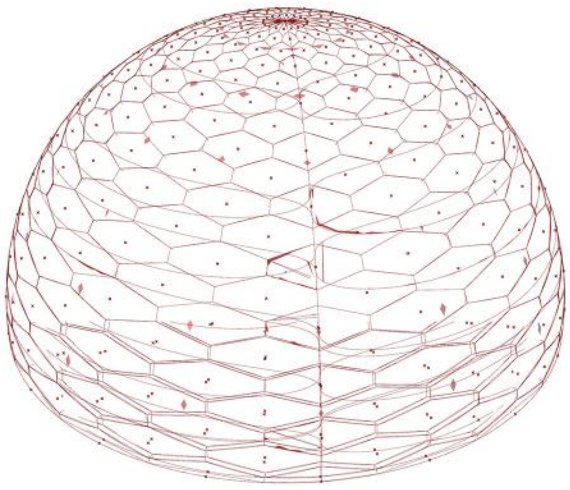


The geometrical issue that arose during the digital computation process was to design a thin curved tile for the surface of a dome. A control in the cohesiveness of the tiles was necessary due to the uniformly of the tile pieces,where the oculus becomes most challenging as the geometry becomes infinitely small and control of the tiles is lost.

POROSITY



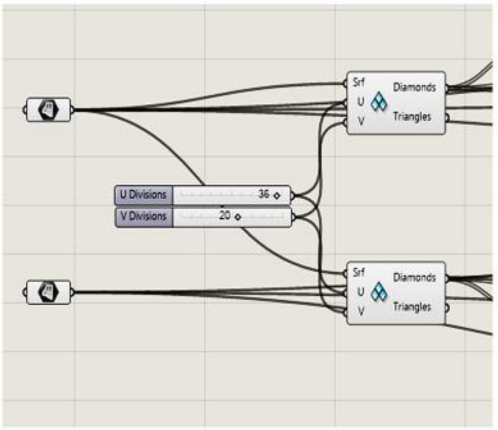
Introduction and control of porosity through a choreography in the apertures that can become spatially receptive and morphologically exciting.



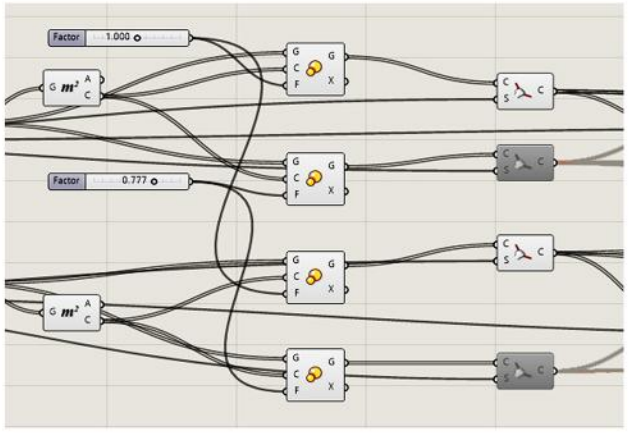
Form finding and use of the hexagonal pattern along with the diagrid created a matted surface to stabilize and reinforce the structure. A diagrid is a rigid framework given its inherited geometry which by virtue becomes a firm base for the application of layers and a stronger geometry form.

In conclusion a tile matting system was created to solve for surface issues in the geometry of a half-circle by creating two geometries that allowed for porosity and layering using digital computation. This allows a solution in the geometry of the oculus by developing prototypes that explore and test the geometry to achieve a greater structural strength with a minimal amount of pieces with a control in variation in thickness of tiles and its center.

DIGITAL COMPUTATION



TILE SIZE AND AMOUNT CONTROL

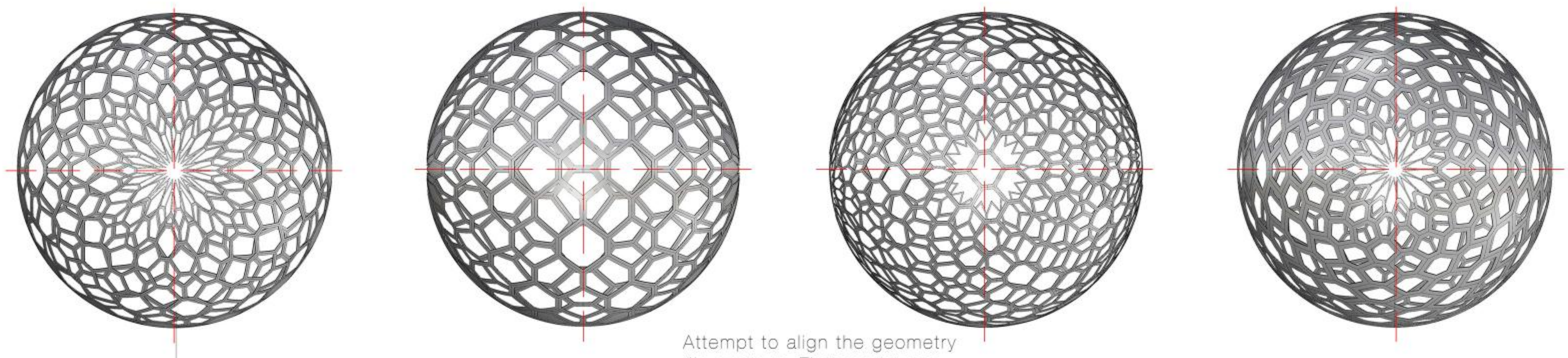


APERTURE SIZE CONTROL

Adrian de Leon | Christopher Laskoski | Marco Martinez

DOME PROTOTYPES

1. FIRST PROTOTYPES

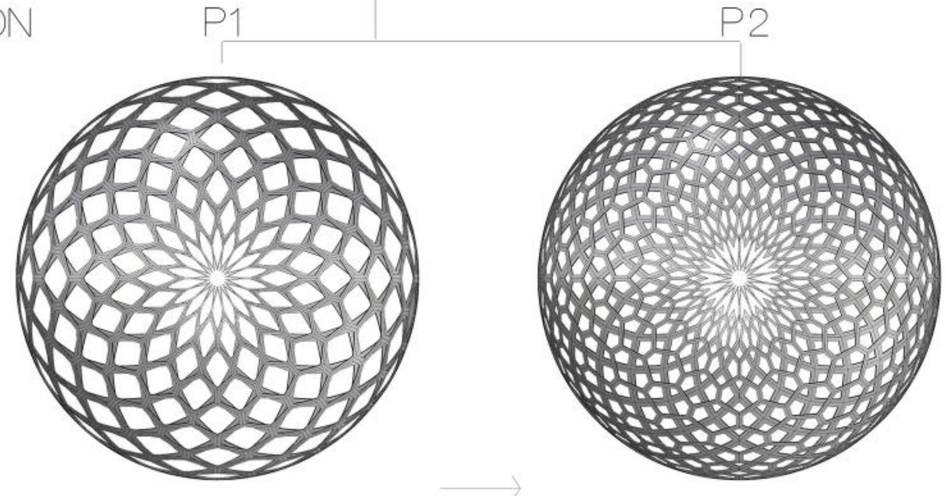


Attempt to align the geometry tile centers. First prototypes only align at center lines.

2. SECOND VERSION

Change in tile size in accordance to layer row with improved control over tile alignment.

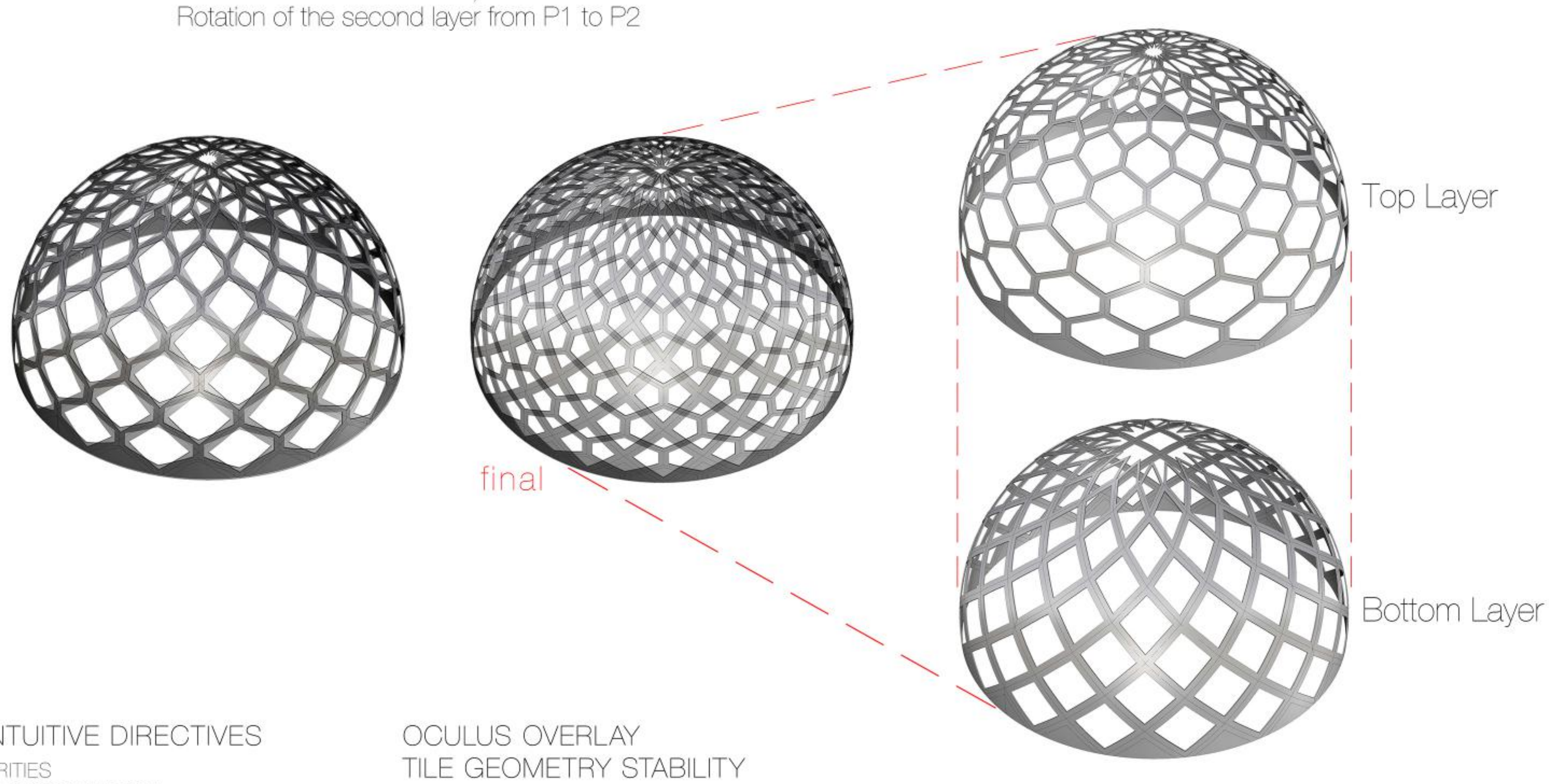
3. THIRD VERSION



Solving by applying two different geometrical surfaces with a higher control in alignment and porosity.

Rotation of the second layer from P1 to P2

LAYERS



CRITERIA

STRUCTURAL INTUITIVE DIRECTIVES
- MINIMIZE IRREGULARITIES
- MAXIMIZE CENTROID COORDINATION
- MAXIMIZE LAYER TO LAYER CONSISTENCY IN PROFILE GEOMETRY

OCULUS OVERLAY
TILE GEOMETRY STABILITY
POROSITY
MINIMAL PARTS

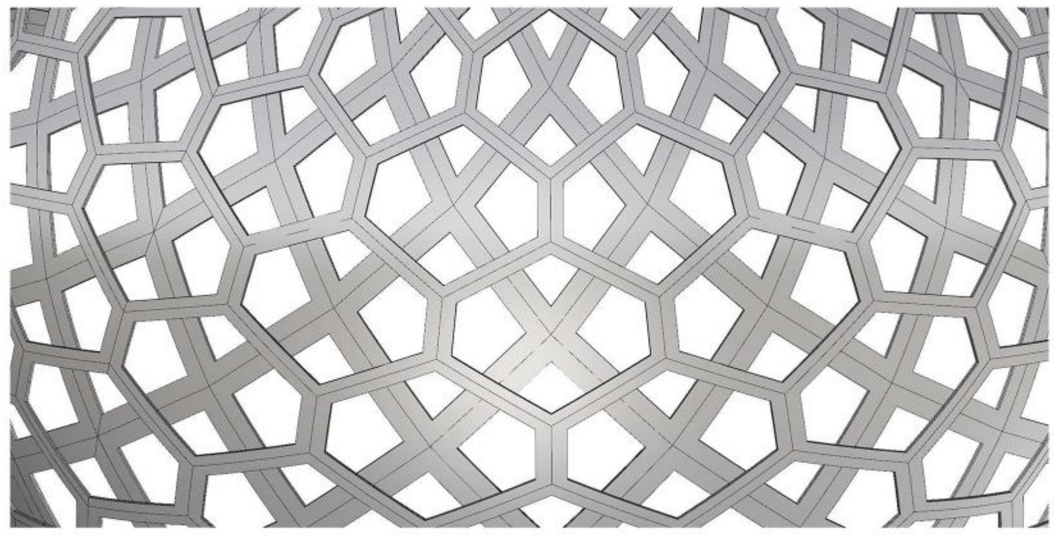
A matted effect is created by layering and the juxtaposition of two different vectors which allows for a more rigid structure with a higher compressive strength while maintaining the thin shell definition and spanning greater distances as a self sustaining structure.

Adrian de Leon | Christopher Laskoski | Marco Martinez

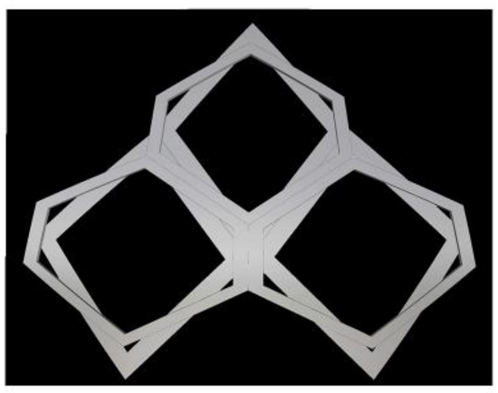
「CAP(c)S」

FINAL DOME

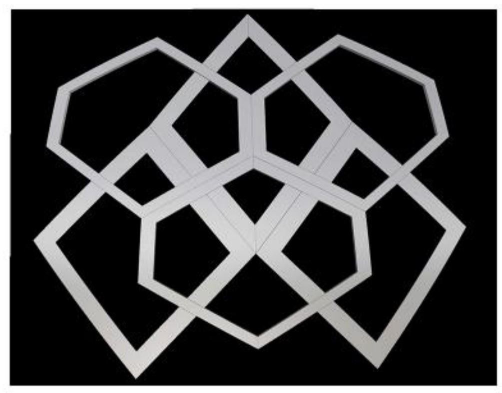
PROTOTYPE 1



PROTOTYPE 2



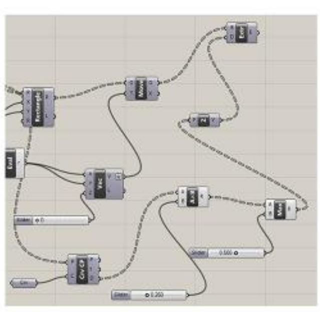
Detail of the layering in prototype 1 demonstrates how the structure is reinforced through the alignment of the matting system with the use of the hexagonal and diamond geometries which reinforce the joints.



Detail of the layering in prototype 2 demonstrates how the structure has a stronger reinforcement the alignment the the center points of the tiles hear by which increasing the strength of the entire structure.

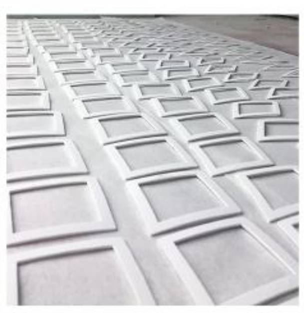
Total number of pieces created for the first layer 162
Total number of pieces created for second layer 180
Total number of pieces created in total 342

PROCESS

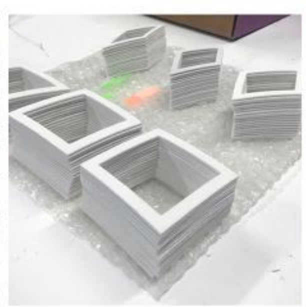


GRASSHOPPER

3D PRINT

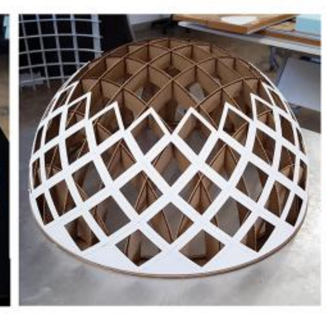


COAT OF
EPSON SALT



APPLICATION OF
PROTECTIVE GLOSS

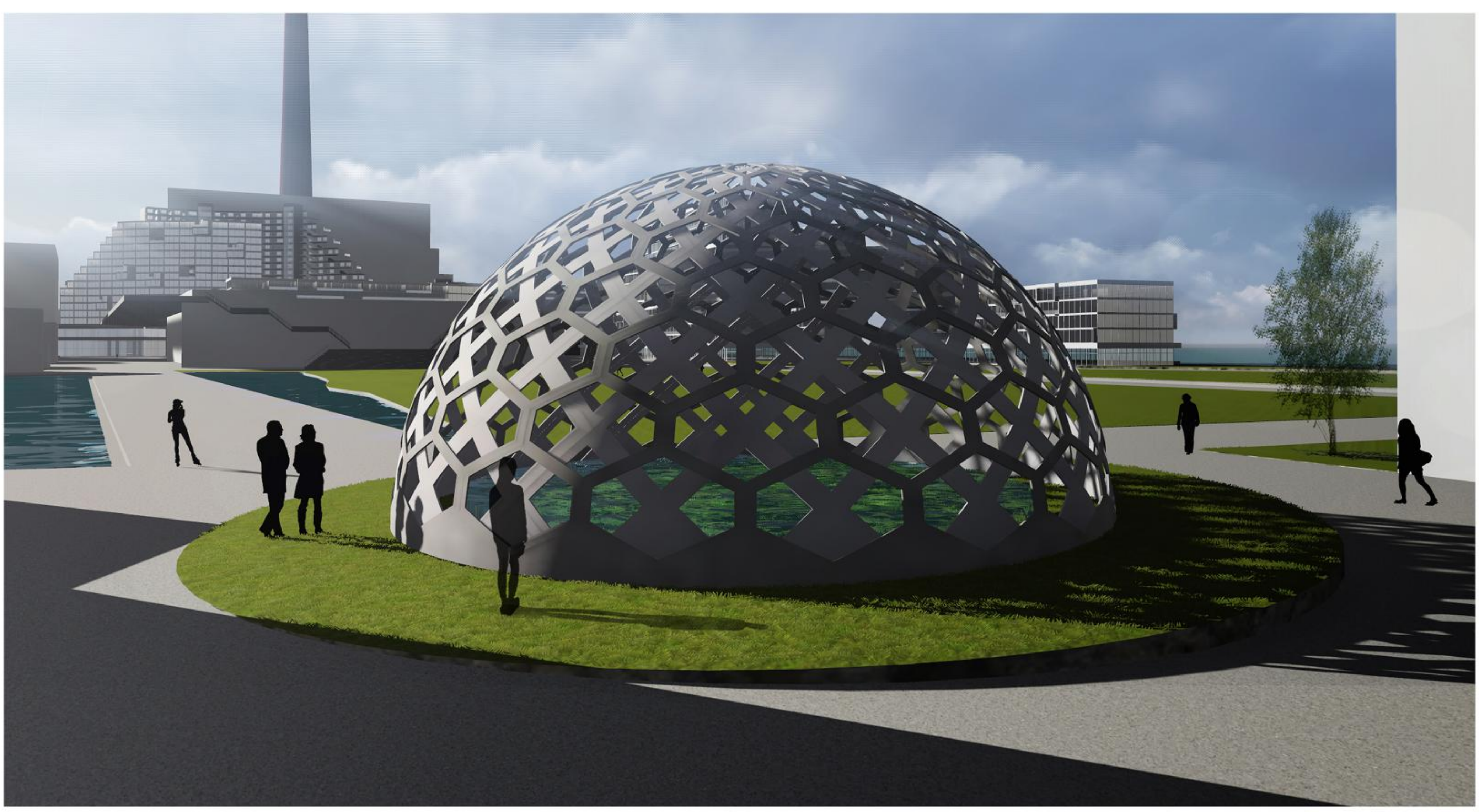
CREATE AND ASSEMBLE
FORM-WORK



BUILD THE
FIRST LAYER

BUILD THE
SECOND LAYER

PERFORMANCE



ASYMMETRICAL VAULTING

VAULT INITIATION AND PROCESS

Architecture requires diverse solutions given the contextual site requirements that require a range of topological diversity that typically requires asymmetrical solutions. The thin-shell allows the production of these topological variations with enhanced surface performance. The design and shape can be found on the site given the context with the system more efficiently. Efficiency is obtained from using the least amount of material,optimized matted system, maximized layer to layer consistency and minimization of irregularities all through digital computation.

PRECEDENT

Analyzing some of the research that has come out of The Block Research Group (BRG) at the Institute of Technology in Architecture, ETH Zürich. Using similar prototypes and concepts through modern and past research that adequately represents the final stage of the research through the design of asymmetric vault.

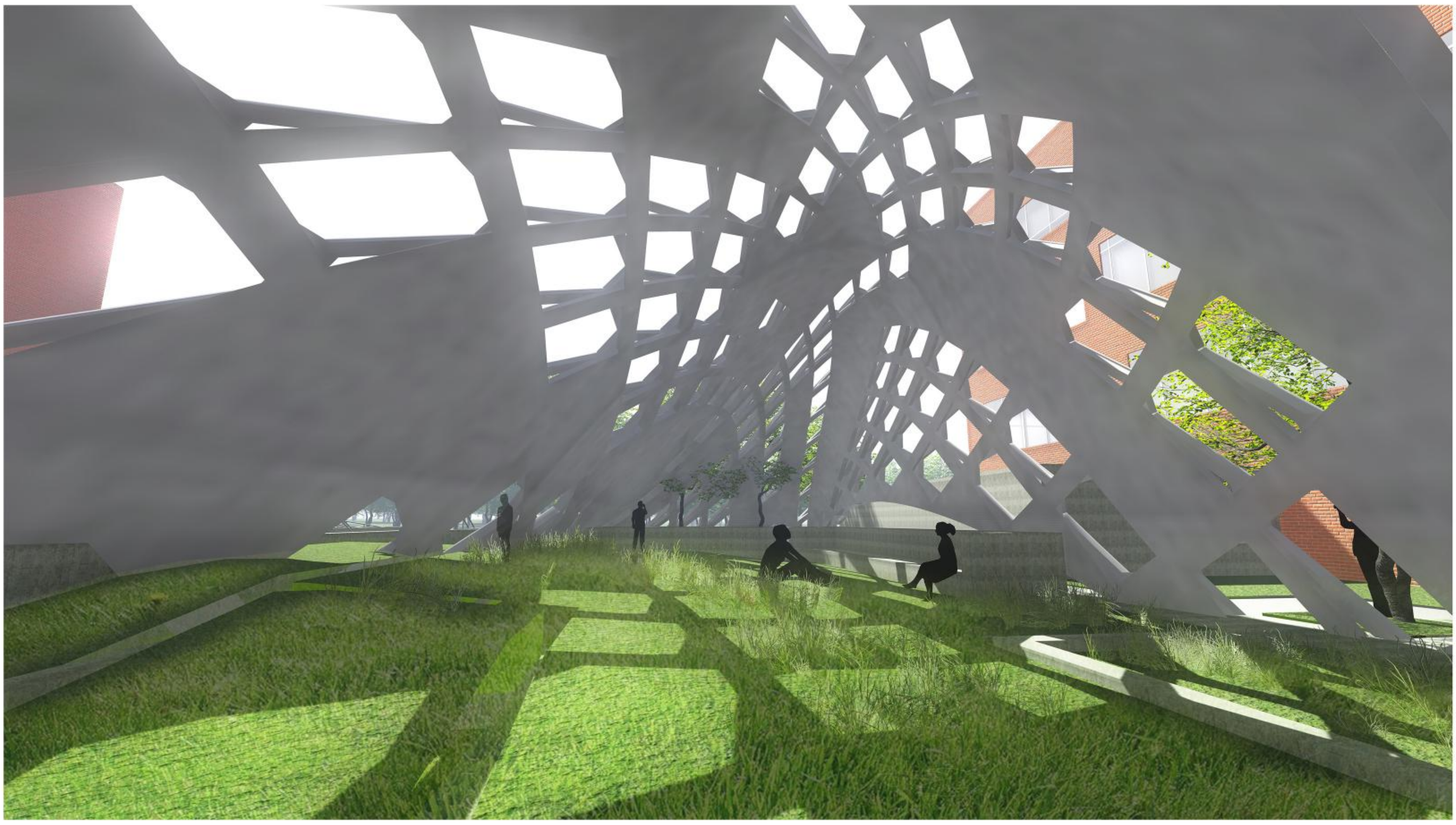


DIGITAL COMPUTATION

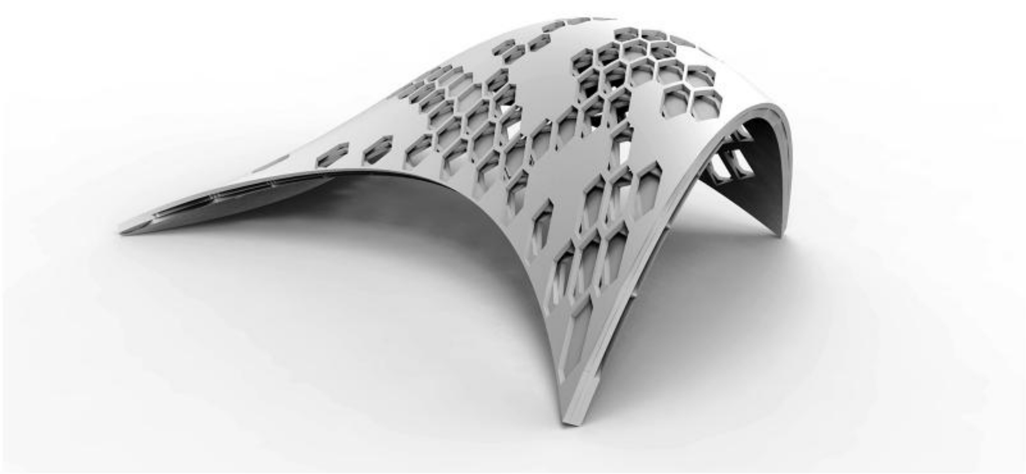
Creating a layered asymmetrical structure that follows stress and structural optimization to achieve a desierable length with a minimal amount of tiles.

LAYERING

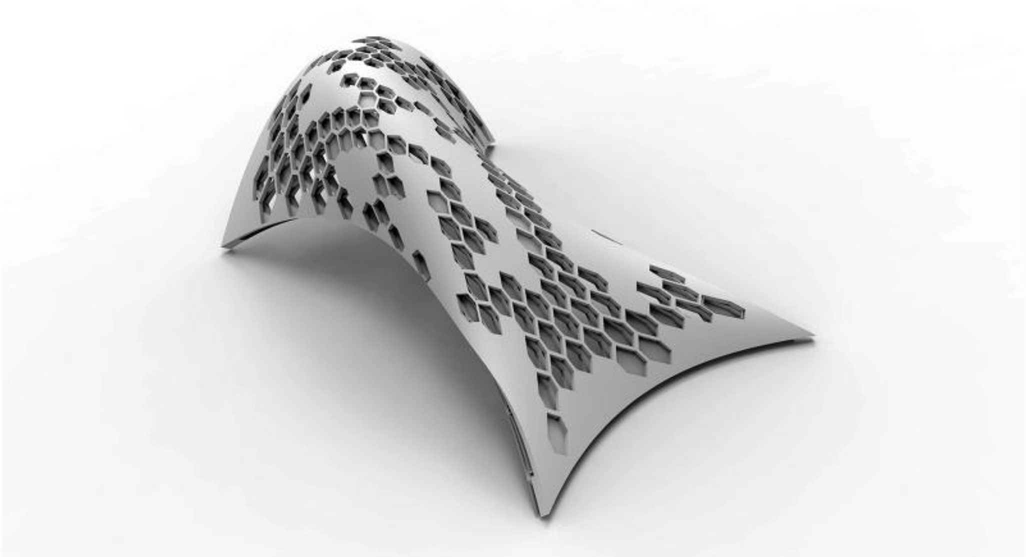
PERFORMANCE



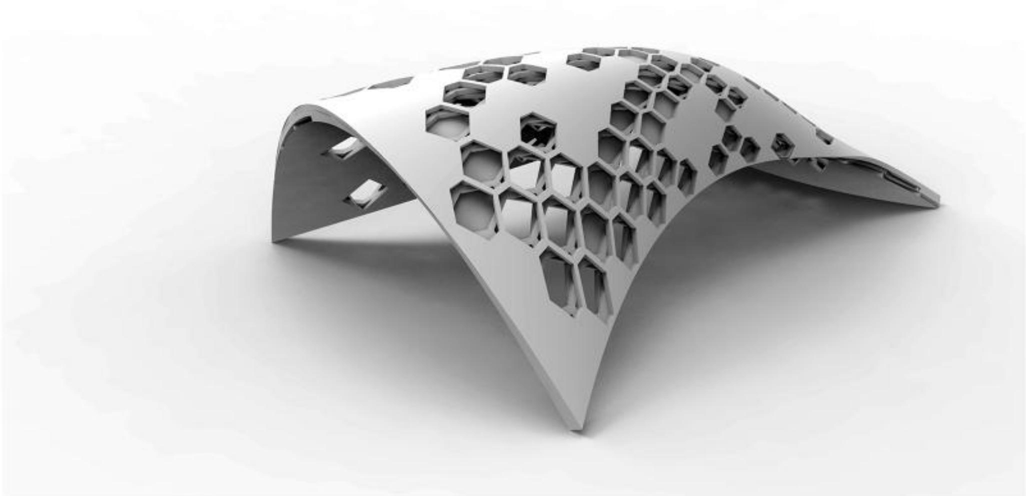
DIGITAL OUTPUT



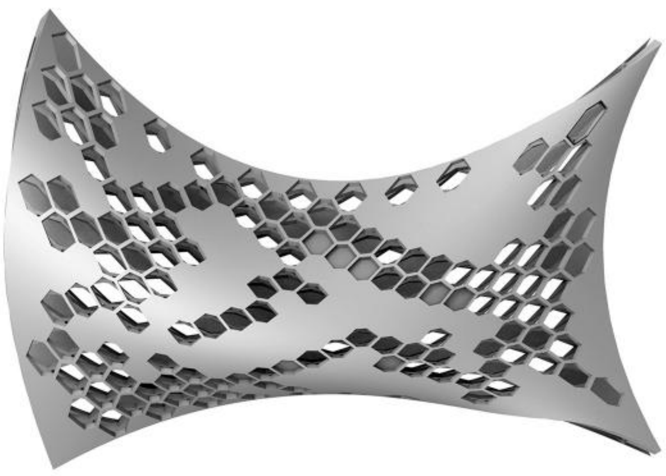
PERSPECTIVE 1



PERSPECTIVE 3



PERSPECTIVE 2



PLAN OF ASYMMETRICAL VAULT