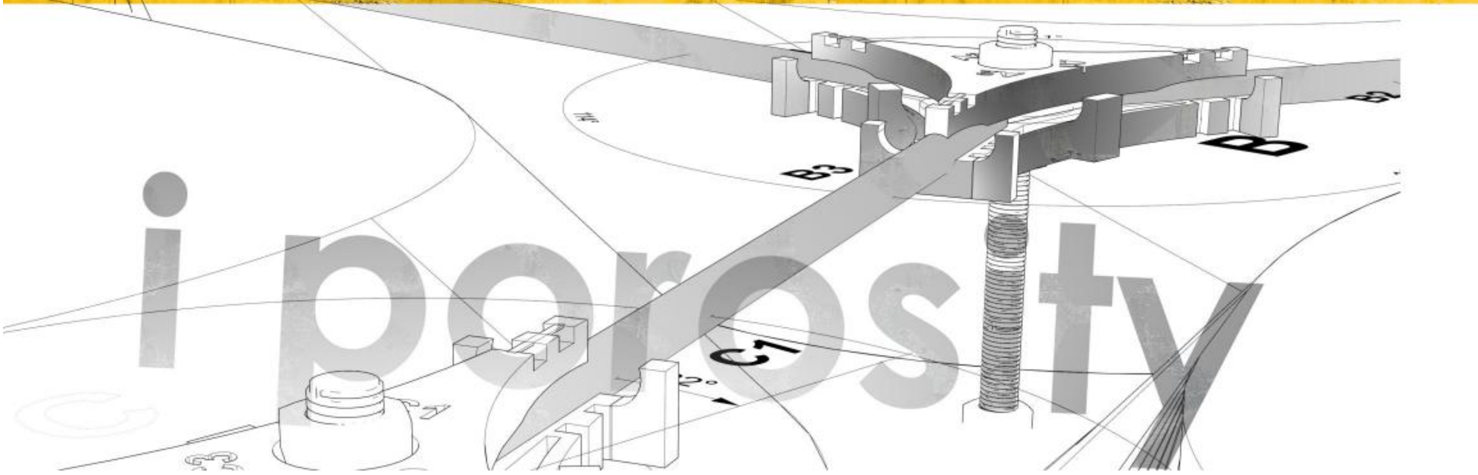
research outline

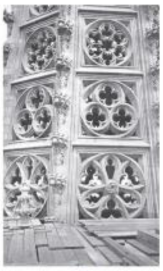


1.1 PRECEDENT

porosity development as a historical and methodological analysis

there are clear examples in the history of art, construction and fabrication for using perforation not only as a decorative element in buildings facades, but also as a performative element that contributes numerous benefits both in terms of comfort and efficiency. It is therefore desirable to integrate porous openings into traditionally opaque concrete facades.

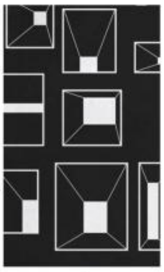
historical precedent ← linguistic precedent → methodological precedent



cologne cathedral

gothic

trefoils and stone tracery serve not only as decoration but a pourous openings for light and ventilation



ronchamp

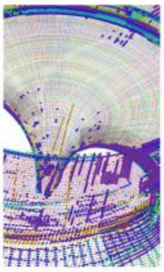
modern

Le Corbusier's cathedral serves as one of the best early examples of porosity in modern concrete facades

0-14

contemporary

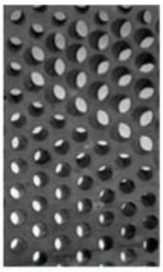
presents a highly organized approach to both justifying and ordering perforation in a concrete facade



ROK

digital

ROK's customized software solutions allow the generation, clustering and handling of complex data sets used to produce detailed reinforcement drawings.



gramazio & kohler

fabrication

robotic fabricaiton techniques are utilized to introduce porosity at oblique angles to achive a variety of results

1.2 JUSTIFICATION

formal logics/queries for research agenda and development outcomes.

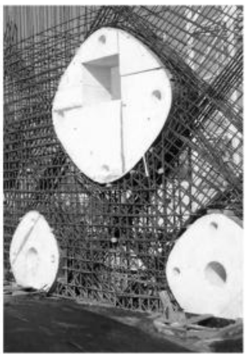
It is imperative that iPorosoity establishes clear motivations and outcomes so as to avoid developing a "false problem", or a research outcome that does not necissarily result in useful knowledge of efficent practice.

thesis

Can greater variability in porosity improve both peformance and aesthetic appeal in prefabricated concrete panels?

If so, will this require different strategies in material reinforcement? can rebar then be ordered in non-uniform arrays in order maximize variation in pororsity and mitigate tensile stress?

Existing strategies for generating pourous opening in concrete facades are often labor intensive and time consuming. Can techniques in parametric and procedural modeling/scripting expedite fabrication pipelines so as to nullify the inherent difficulties in properly reinforcing concrete panels with non-uniform pourous openings?

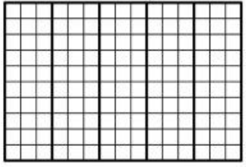


iPorosity proposes that rebar bent to specific angles and then joined via a series of intelligent clips could thusly faciliate a diverse range of porosity options. Furthermore, digital workflows allow for a higher degree of precision in terms of ordering rebar in a manner specific to the porosity; nullifying the need for intermediary or secondary rebar arrays.

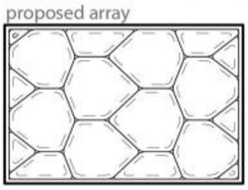
Available software allows us to simulate structural stresses in advance, and therefore account for potential difficulties by tailoring the model geometry to more efficiently distribute loads.

As seen in the proposed array, final research outcomes would result in a pre-fabricated concrete panel with a high degree of porosity.

conventional array



proposed array



1.3 PROCESS

Vectors that establish pertinent task objectives.

The iPorosity team has identified three areas of consideration that each require equal and consistent attention.

Digital processes relate to the application of parametric and 3D modeling tools as they facilitate both abstract and simulated conditions

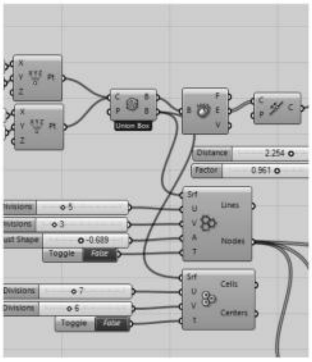
Technical processes relate to the collection of specific information, and then the application of that information as it pertains to generating working fabrication documents.

Testing processes relates to bot the digital and physical testing of 3D or physical geometry.

digital process

Grasshopper provides the iPorosity team with the appropirate platform to accomplish multiple objectives. One, the generation and control of the voronoi cellular subdivision. Two, the abstract represenation of the final rebar layout. And three, the geometry that will ultimately be required to mill the necessary formwork for casting tests.

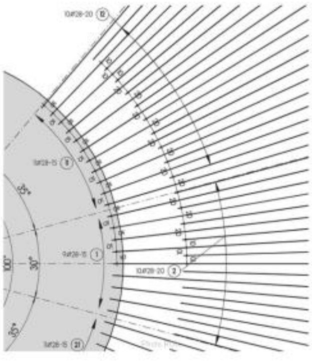
Furthermore, it may be possible to develop definitions that can generate perscriptive information and models to help facilitate fabrication.



technical process

It is necessary to amass a large amount of technical data so as to better understand the limitations of both the materials and structures we plan on utilizing. This means generating a full range of specifications that demystifies the fabrication process and provides a third party with the necessary information to replicate our processes.

This will ultimately require detailed drawings of clips, rebar assemblies, formwork geometry, and concrete mixes.



testing process

Much of the testing will mostly like require some form of digital simulation in order to prooperly anticipate the physical forces that may be acting upon our final fabricated panel. Our team seeks to produce simulated models of both our clips geometry and rebar array.

Kangaroo for Grasshopper provides us with a suite of physical modeling tools that give us near instaneous feedback, and freely available structural analysis porgrams can identify areas of potential structural failure.

precedent studies

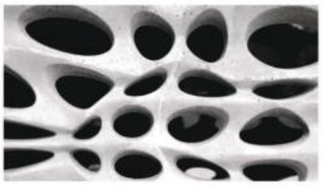
2.1 PRECAST POROSITY

Location	UTA Library, Arlington
Year	2013
Professor	Brad Bell
Students	Austin Ede + Khang Nguyen

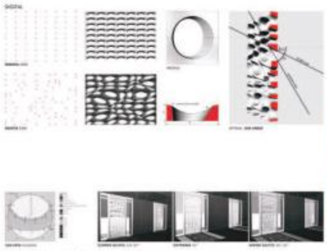
This research project explores the use of digital fabrication technology and parametric modeling to investigate the production of concrete brise soleil panels.

Specifically the research examines how the digital toolset can be used to produce repetitive panels with non-standard patterning as pre-cast concrete panels. The pre-cast industry relies upon efficiency found typically in repetition and simplified geometric shapes to produce achievable molds. This in turn has a predictable outcome on the readily found geometries typically found in precast components.

However, when linked with a more sophisticated methodology and mold making materials it is our working hypothesis that non-standard patterning could override the primary paneling and produce a highly 'organic' panel –that is still capable of meeting all other programmatic requirements.



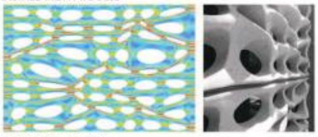
PRECEDENTS CONTEXT



DIGITAL ANALYSIS

MOLD MAKING AND CASTING

INSTALLATION PROCESS



GEOMETRY ANALYSIS

FINAL PRODUCT

2.2 STUTTGART 21'S REINFORCEMENT

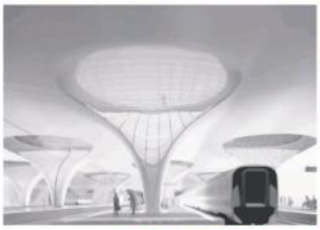
Location	Stuttgart, Germany
Year	2011
Project Partners	M. Knauß, S. Oesterle, M. Rippmann

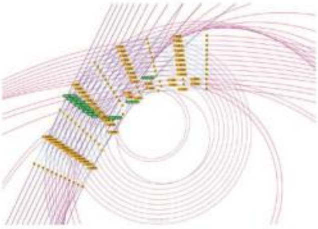
The new central station for the Stuttgart 21 infrastructure project by Ingehoven Architects with Frei Otto features complex double curved concrete geometries.

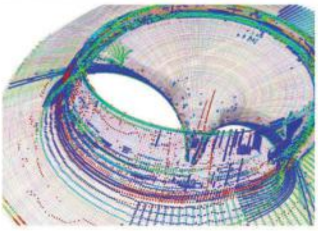
The roof transforms into 28 structural columns thus providing daylight openings for the underground station. ROK's scope of work ranges from shape optimization processes for the reinforcement geometry to automatic reinforcement layout and planning of over 10000 reinforcement elements per column.

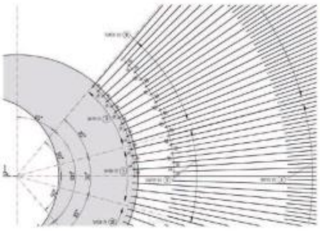
ROK's customized software solutions allow the generation, clustering and handling of complex data sets used to produce detailed reinforcement drawings. ROK was commissioned by the engineers Werner Sobek Stuttgart.

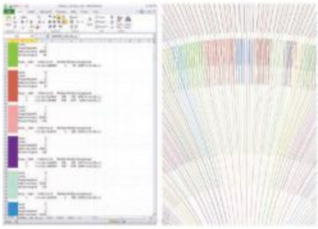
Advantages: Indicates that it is possible to order complex arrays of curved rebar so as to generate Non-Euclidean forms that are both structurally sufficiency and supple in appearance











2.3 THE PERFORATED WALL

Location	School Of Arch. in Zurich, Switzerland
Year	2006
Architect	Fabio Gramazio + Mathias Kohler

Advantages: Indicates that concrete is suficiently rigid enough to sustain substantial material subtraction while remaining structurally rigid. Porosity can be utilized to generate a wide range of surface effects.

"In the "oblique hole" course (Das shiefe Loch), students had to allocate 2,000 holes over an irregular polygonal volume. The objective was to examine the architectural potential of spatial perforations produced by distributing a large amount of circular openings in an irregularly shaped form. The production tool was a a milling spindle mounted on a robot hand; the robot's ability to drill holes at any angle to the surface expanded the design possibilities from merely distributing the holes to also defining the their direction. Various algorithmic tools for distributing the holes had to be developed, as it was impractical to process such a large number of perforations with conventional computer-aided design (CAD) technology.

The digitally generated design data was translated into production data for the robot by a custom-developed post-processor. The production data for each individual hole consisted of its position in space and a vector that described the tool's drilling path through the material.

(From Emerging Possibilities of Testing and Simulation Methods and Techniques in Contemporary Construction Teaching edited by Maria Voyatzaki (Pages 36-39)

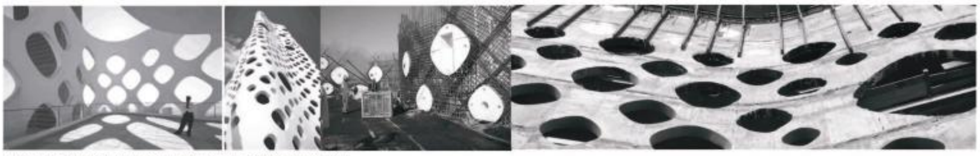
2.4 0-14 TOWER

Location	Dubai, United Arab Emirates
Year	2007-2009
Architect	Jesse Reiser + Nanako Umemoto

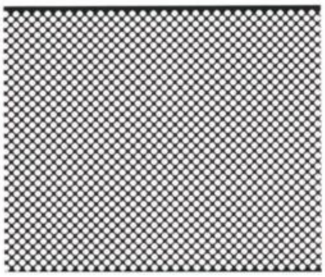
The holes are achieved by introducing computer numerically cut polystyrene void forms into the rebar matrix, and sided with modular steel slip forms prior to the concrete pour. Super-liquid concrete is then cast around this fine meshwork of reinforcement and void forms resulting in an elegant perforated exterior shell.

The 0-14 project represents a novel facade development that successfully utilizes a matrix of steel reinforcement in tandem with non-ordered perforation. From a methodological approach, the projects presents our team with several interesting considerations. Both the way in which the pattern was developed and the means by which it mitigates structural loads is intentionally ambiguous in terms of its visual reading. Conceptually, the system attempts to inhabit a middle ground between structural expressionism and structural rationalism. Our team must carefully examine how formal design considerations regarding the perforation can adequately nullify the risk of 'pattern-making' as we navigate the intentionality of the scripting language vs. performance outcome.

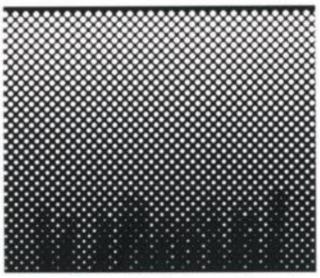
Furthermore, the aesthetic novelty of the facade, and the enthusiastic response to it, demonstrates a clear need to explore dynamic and exciting alternatives to conventional facade design. From a structural standpoint, we see that is also possible to economically integrate non-uniform porous openings while simultaneously mapping a rebar matrix to account for those openings.



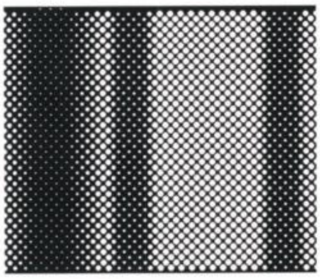
source: http://code.we-designs.org/images/RUR_O-14_Facade.jpg



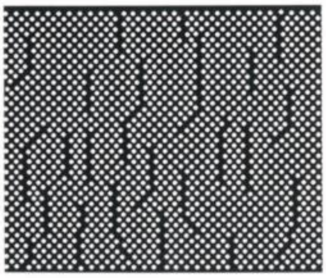
undifferentiated



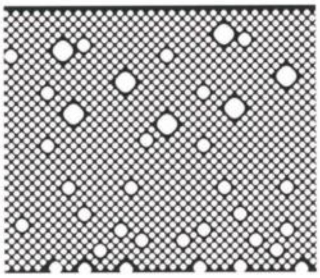
structurally optimal



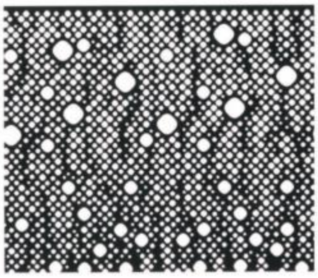
optimal daylighting



material change - decreased porosity



material change - increased porosity



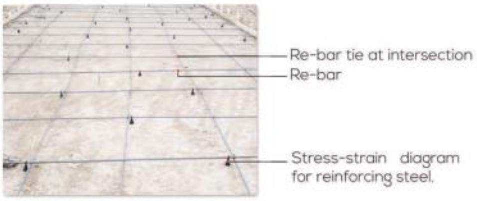
combined result

material & behavior

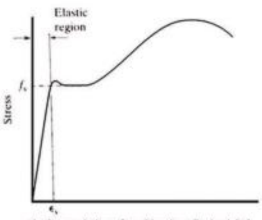
3.1 TRADITIONAL REINFORCING

Traditional Re-enforcing concret is a concret mixture that adds the additional material of re-bar/reinforcing steel. Concrete by nature is great in compression strength, but cannot take on a great deal of tensile stress with out cracking, making it a brittle material. The use of rebar makes up for the deficiency in a poured concrete member.

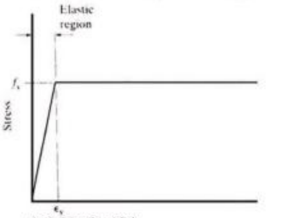
The steel bars are are round and deformed with threaded/ rib progections n its surface. This unique feature of the re-bar adheres to the composition of the concrete producing a cohesion of the yield tensile strenghth of steel and the high compressive strength of concrete. this application in the end produces a material that performes well in both



Typical re-bar layout

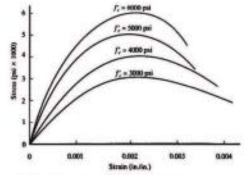


strain as determined by tensile test (a)

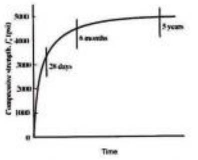


strain idealized (b)

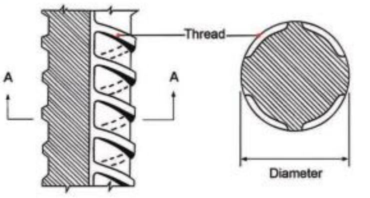
Stress-strain diagram for reinforcing steel.



TYPICAL STRESS -STRAIN CURVE



STRENGTH-TIME RELATIONSHIP



Reinforcing Steel

Type of steel and ASTM specification number	Bar sizes	Grade	Minimum Tensile strength (psi)	Minimum yield strength f_y (psi)	Yield strain ϵ_y
Billet Steel A615	Nos. 3-6	40	70,000	40,000	0.00138
	Nos. 3–18	60	90,000	60,000	0.00207
	Nos. 6–18	75	100,000	75,000	0.00259
Low-Alloy Steel A706	Nos. 3–18	60	80,000 (Min.: 1.25 f_y)	60,000 (Max.: 78,000)	0.00207

Bar number	3	4	5	6	7	8	9	10	11	14	18
Unit weight per foot (lb)	0.376	0.668	1.043	1.502	2.044	2.670	3.400	4.303	5.313	7.65	13.60
Diameter[a] (in.)	0.375	0.500	0.625	0.750	0.875	1.000	1.128	1.270	1.410	1.693	2.257
Area (in.^{2})	0.11	0.20	0.31	0.44	0.60	0.79	1.00	1.27	1.56	2.25	4.00

The nominal dimensions of a deformed bar diameter and area equivalen to those of a plan round bar having the same weight per foot as the deformed bar.

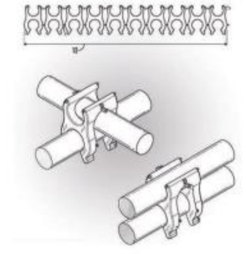
3.2 POLYSTYRENE RESIN

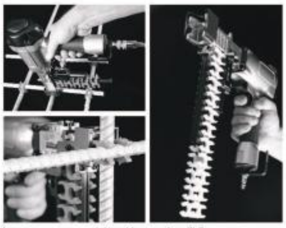
Polystyrene resin is a thermoplastic polymer produced from styrene, a petroleum derived liquid hydrocarbon. The resin possesses low softening temperatures, good wear characteristics, a high refractive index, and excellent electrical insulation properties. Polystyrene resin is used in a wide range of manufacturing processes such as injection molding, sheet and film extrusion, and expanded foam extrusion. Items produced from polystyrene resins are found in abundance in a diverse range of environments. The storage and eventual disposal of polystyrene resin products requires considerable care and planning due to substantial fire hazards and extremely low biodegradability characteristics.

http://www-oc.chemie.uni-regensburg.de/OCP/ch/chv/oc22/script/003.pdf

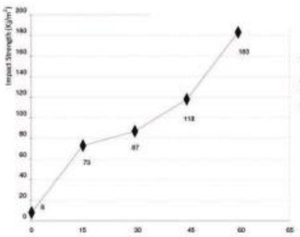
Polystyrene is characterized by excellent electrical insulation properties, relatively high resistance to water, high refractive index, clarity, and low softening temperature.

http://www.fte.edu.iq/ar/upload/upfile/887PROPERTIES%20OF%20POLYSTYRENE%20RESIN%20REINFORCED%20BY.pdf



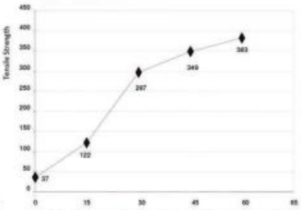


images source: http://www.kodiklip.com



IMPACT STRENGTH VALUE VS. FIBERS CONTENTS.

< **Fig.1** The impact strength considered low to the resins due to brittleness of these materials ,but after reinforcing it by fibers the impact strength will be increased because the fibers will carry the maximum part of the impact energy which exposition on the composite material .All this will raise and improved this strength .The impact strength will continue to increase with increased of the fibers reinforcing percentage *(Sadeq, 2011)*.



TENSILE STRENGTH VALUE VS. FIBERS CONTENTS

< **Fig. 2** The resin considered as brittle materials where its tensile strength is very low as shown in this figure ,but after reinforcing by fibers this property will be improved greatly ,where the fibers will withstand the maximum part of loads and by consequence will raise the strength of composite material .The tensile strength will be increased as the fibers percentage addition increased , where these fibers will be distributed on large area in the resin *(Rao, 2012)*.

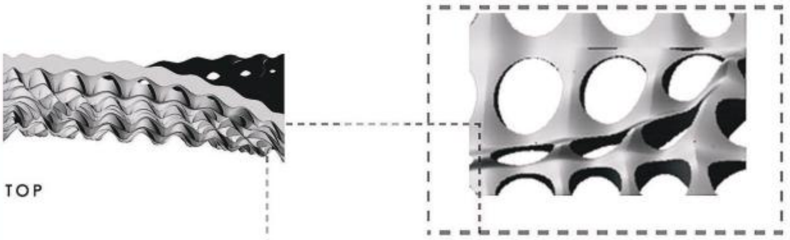
3.3 STRESS ON OPENING

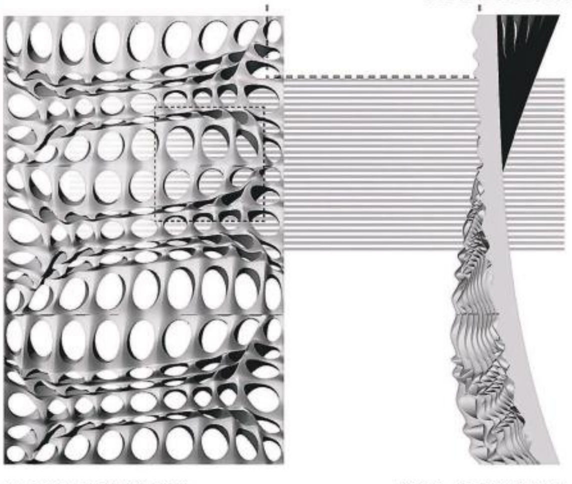
Placing a hole in a structure creates a point of high stress concentration when subjected to an applied load. The effect it has on the local applied stress distribution is dependent on the shape of the hole which will change the stress concentration factor, or stress multiplier, when analyzing the effect on fatigue life. Figure (A) shows the localized stress distribution around a circular hole. When there are multiple holes in close proximity to each other, the respective stress concentration factor for these configurations will be different when the holes are oriented differently to the applied stress shown Figure B.

When two adjacent holes are oriented perpendicular to the applied load, the stress concentration factor is elevated above that of a single hole for all hole spacing's and therefore are more critical in a fatigue design case. For holes in-line with a load applied in the vertical plane the stress concentration factor is less than for a single hole.

Source:

http://www.fatiguetech.com/news_newsletters_april_2011.html





FRONT ELEVATION

SIDE ELEVATION

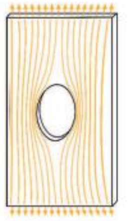


FIG. A

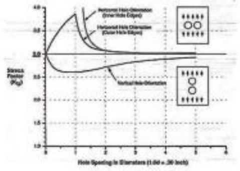
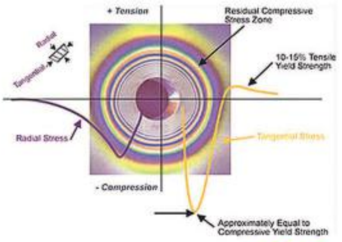


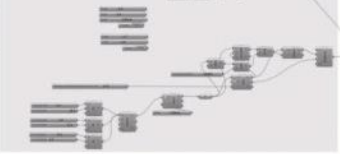
FIG. B



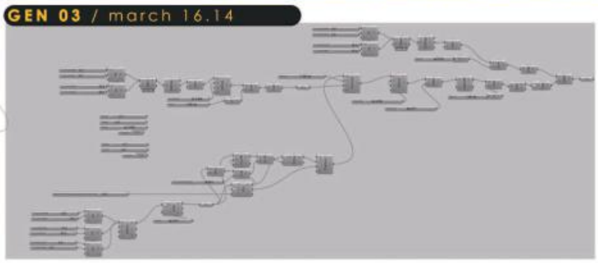
patrametric development

GEN 01 / march 02.14

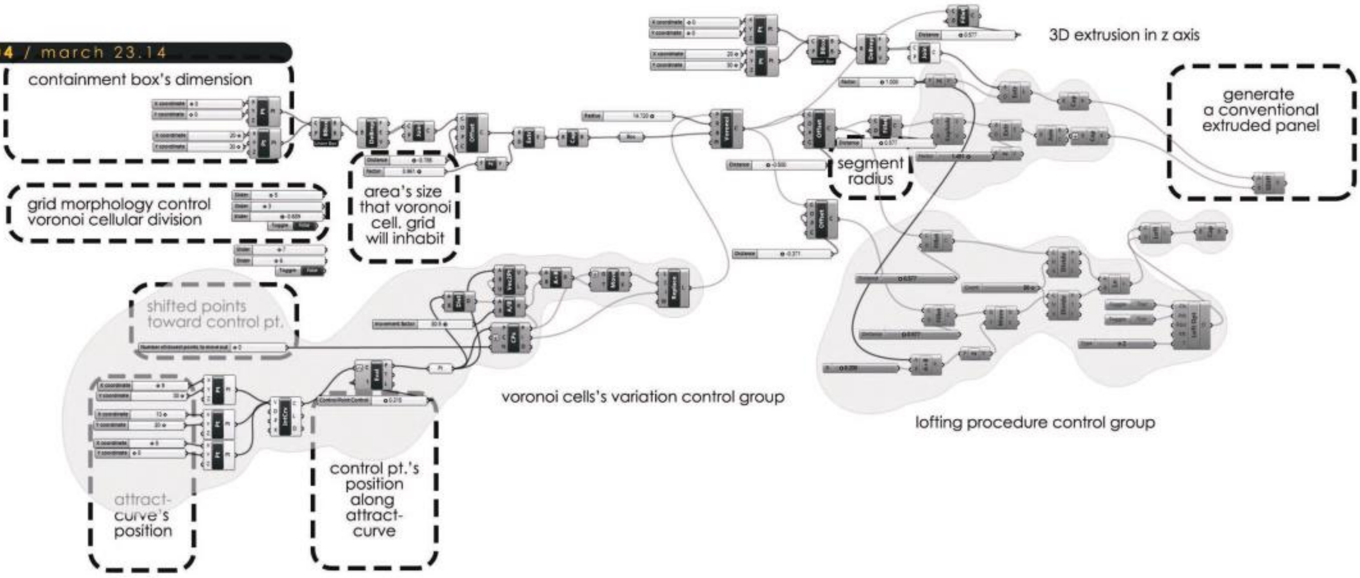
GEN 02 / march 09.14



GEN 03 / march 16.14



GEN 04 / march 23.14



3D extrusion in z axis

containment box's dimension

generate a conventional extruded panel

segment radius

grid morphology control voronoi cellular division

area's size that voronoi cell. grid will inhabit

shifted points toward control pt.

voronoi cells's variation control group

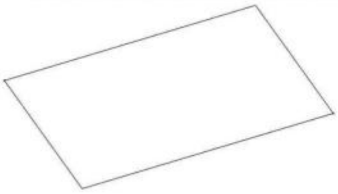
lofting procedure control group

attract-curve's position

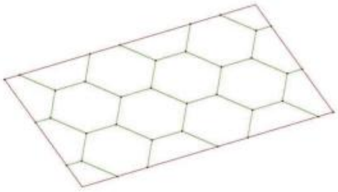
control pt.'s position along attract-curve

mold development

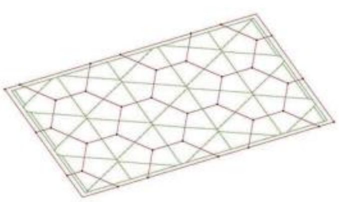
DIGITAL DEVELOPMENT PROCESS



step 01



step 02



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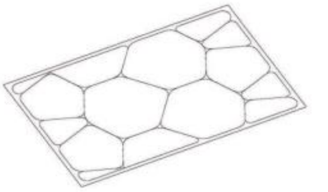

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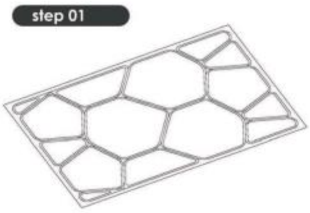

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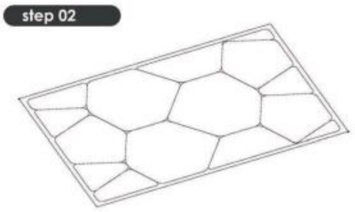

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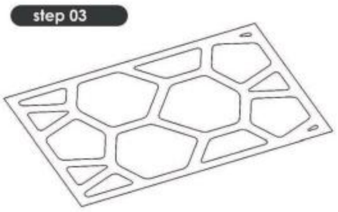

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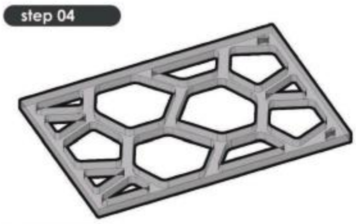
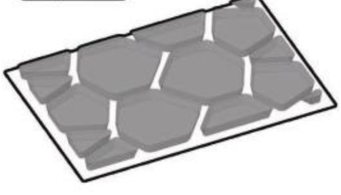


step 08



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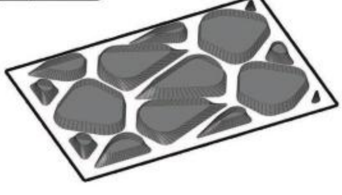

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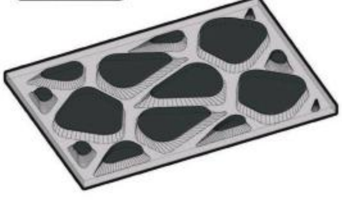
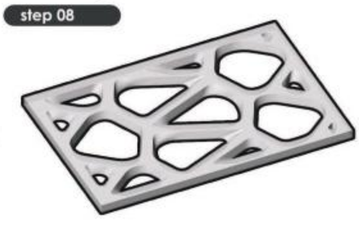


step 11



step 12

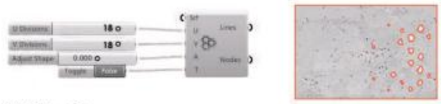
SMALL SCALE CASTING

sealing component

panel configuration

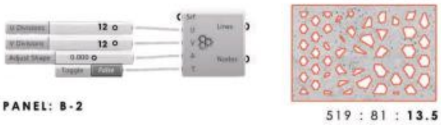
PANEL: A-1 600 : 0 : **0**

PANEL: A-2 598 : 2 : **0.3**

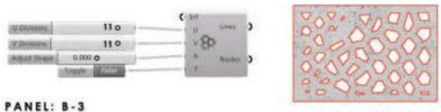


PANEL: A-3 595 : 5 : **0.8**

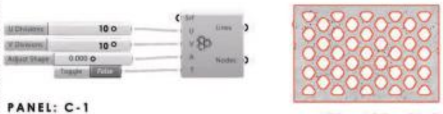
PANEL: B-1 579 : 21 : **3.5**



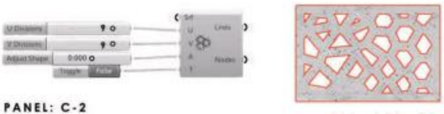
PANEL: B-2 519 : 81 : **13.5**



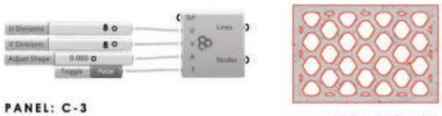
PANEL: B-3 491 : 109 : **18.2**



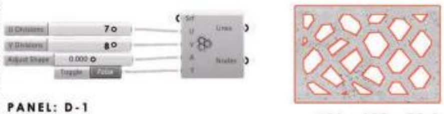
PANEL: C-1 473 : 127 : **21.2**



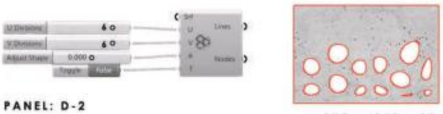
PANEL: C-2 444 : 156 : **26**



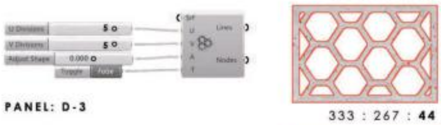
PANEL: C-3 409 : 191 : **32**



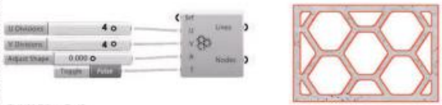
PANEL: D-1 401 : 199 : **33.1**



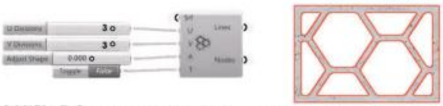
PANEL: D-2 357 : 243 : **40**



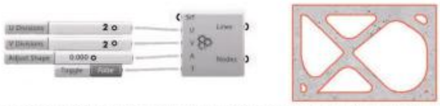
PANEL: D-3 333 : 267 : **44**



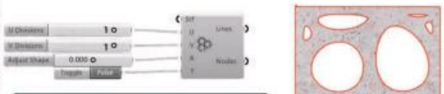
PANEL: E-1 291 : 309 : **51.5**



PANEL: E-2 258 : 342 : **57**

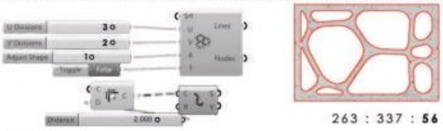


PANEL: E-3 216 : 384 : **64**

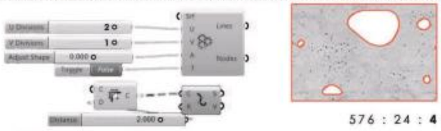


VARIATIONS OF GEOMETRIES GENERATED BASED ON **QUANTITY**

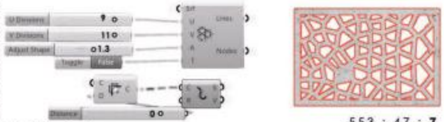
PANEL: F-1 334 : 266 : **44.3**



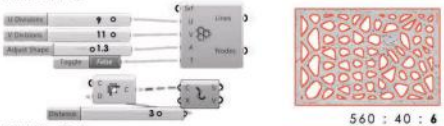
PANEL: F-2 263 : 337 : **56**



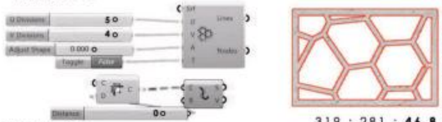
PANEL: F-3 576 : 24 : **4**



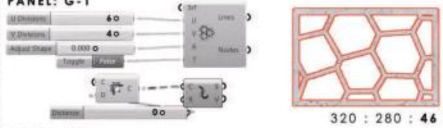
PANEL: G-1 553 : 47 : **7**



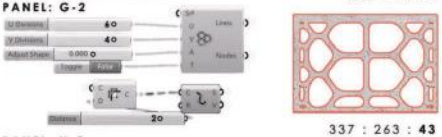
PANEL: G-2 560 : 40 : **6**



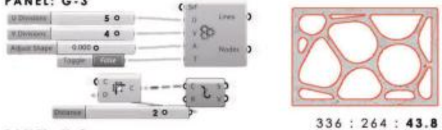
PANEL: G-3 319 : 281 : **46.8**



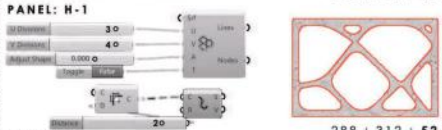
PANEL: H-1 320 : 280 : **46**



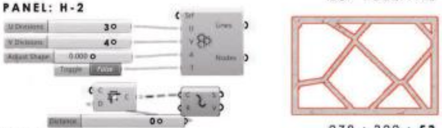
PANEL: H-2 337 : 263 : **43**



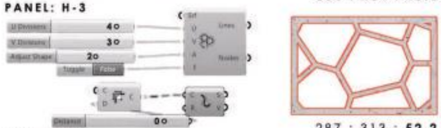
PANEL: H-3 336 : 264 : **43.8**



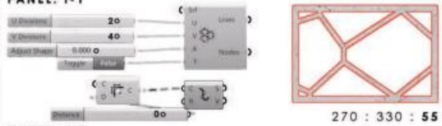
PANEL: I-1 288 : 312 : **52**



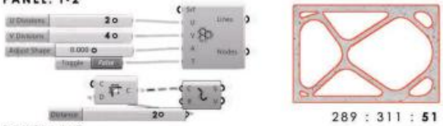
PANEL: I-2 278 : 322 : **53**



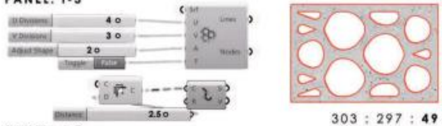
PANEL: I-3 287 : 313 : **52.2**



PANEL: J-1 270 : 330 : **55**



PANEL: J-2 289 : 311 : **51**



PANEL: J-3 303 : 297 : **49**

VARIATIONS OF GEOMETRIES GENERATED BASED ON **PROXIMITY**

POROSITY CALCULATION

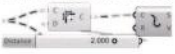
based on ratio between solid and void

270 : 330 : 55

MASS (mm³)
VOID (mm³)
POROSITY VALUE (%)

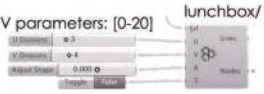
LEGEND

curve/ fillet distance [0-3]

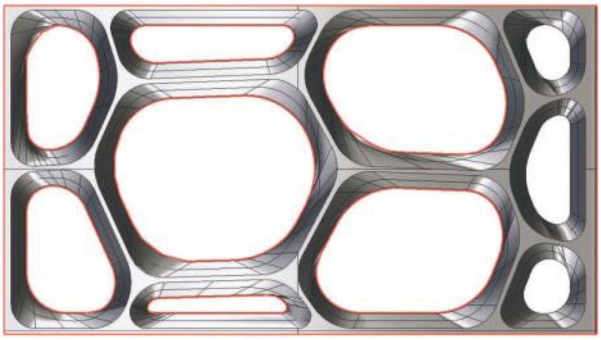


UV parameters: [0-20]

lunchbox/ hexagon structure



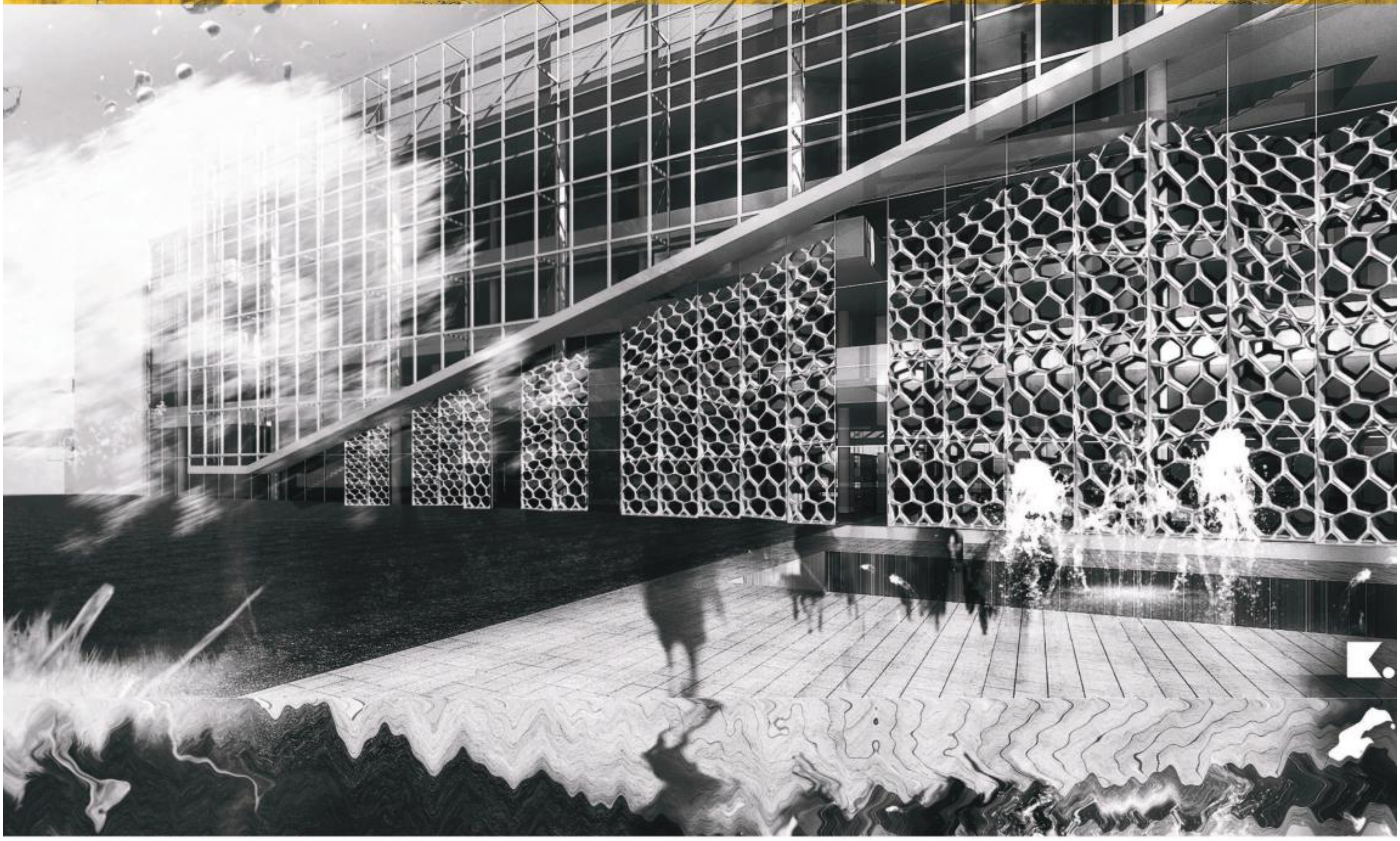
FINAL GEOMETRY



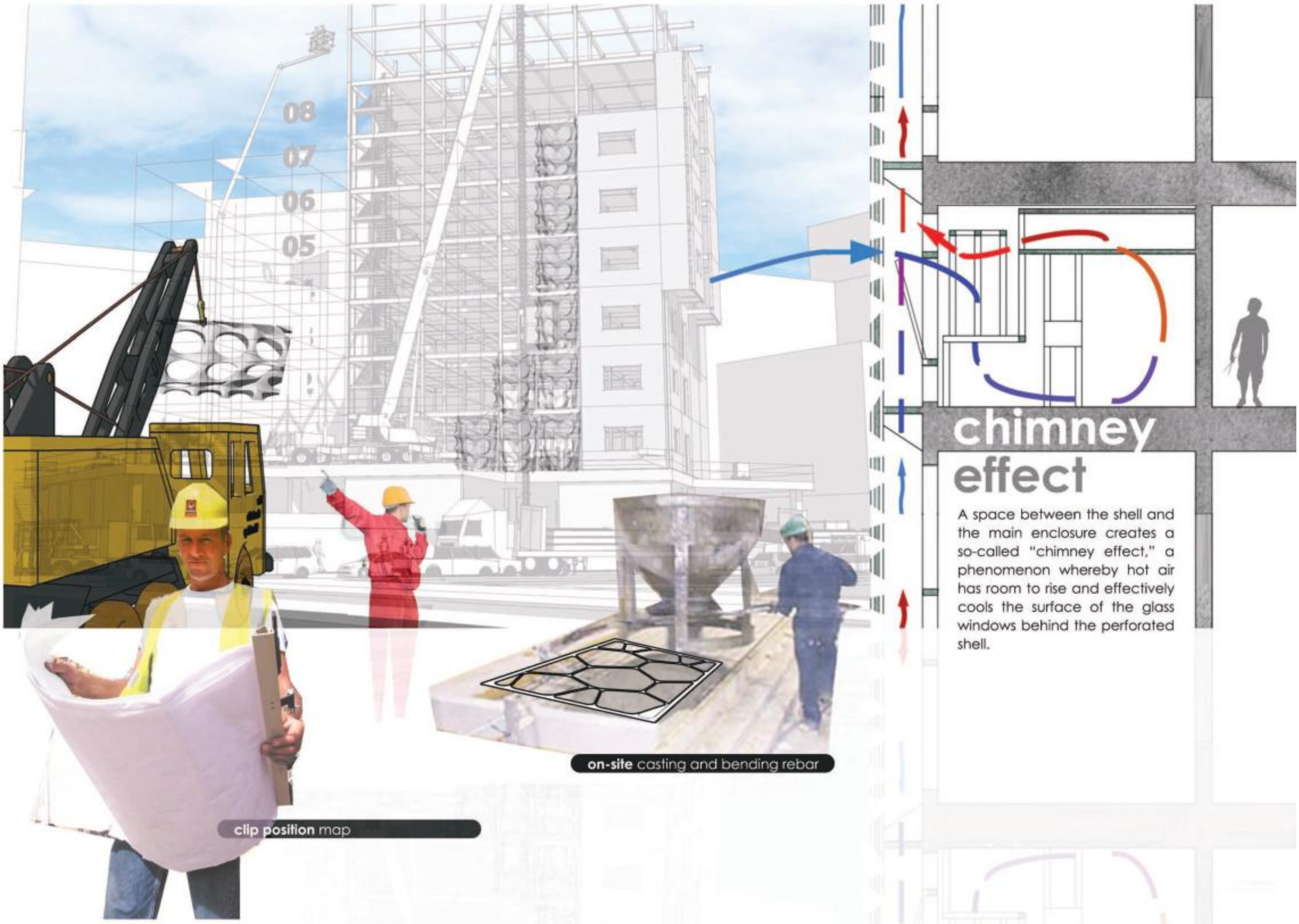
DEVELOPED FROM PANEL **J-3** BUT IN LARGER SCALE : **4'-5" X 8'-0"**

+ UTILIZED A REASONABLE / MINIMAL NUMBER OF CLIPS
+ IDEAL AMOUNT OF POROSITY
+ IDEAL AMOUNT OF VARIATION IN POROSITY
+ IDEAL QUALIFIED IN TERM OF MASS VS VOID AND THE WORKABILITY OF THE STRUCTURAL SEGMENTS

visualization



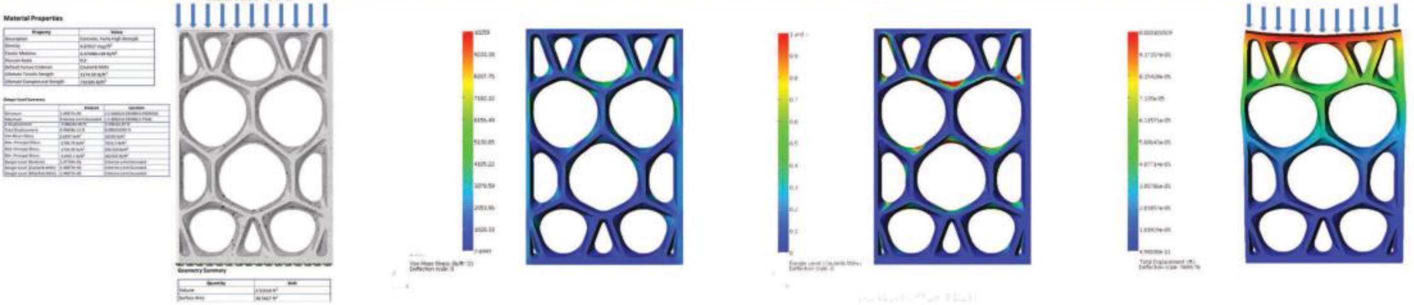
practical assemply concept



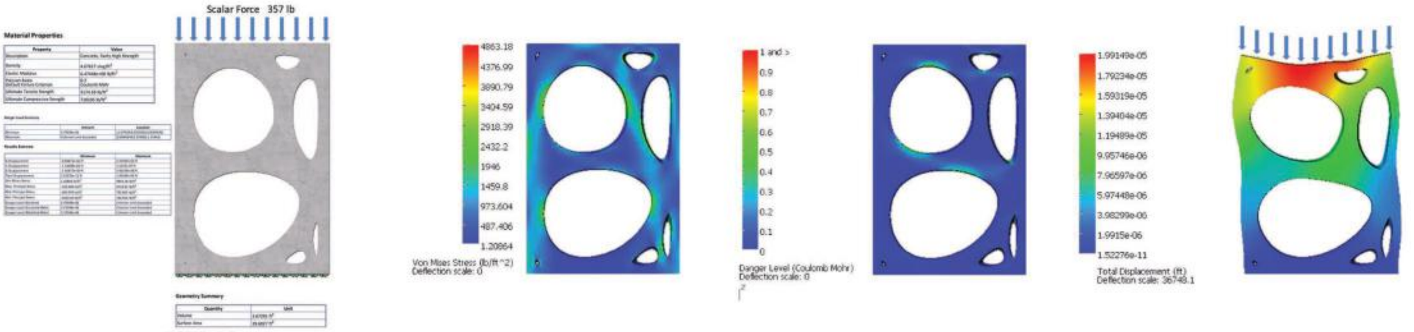
chimney effect

A space between the shell and the main enclosure creates a so-called "chimney effect," a phenomenon whereby hot air has room to rise and effectively cools the surface of the glass windows behind the perforated shell.

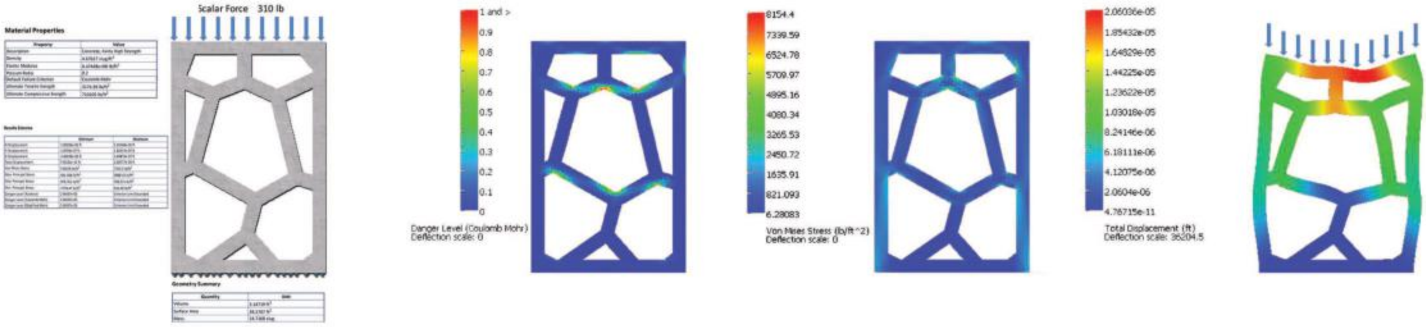
Structural analysis



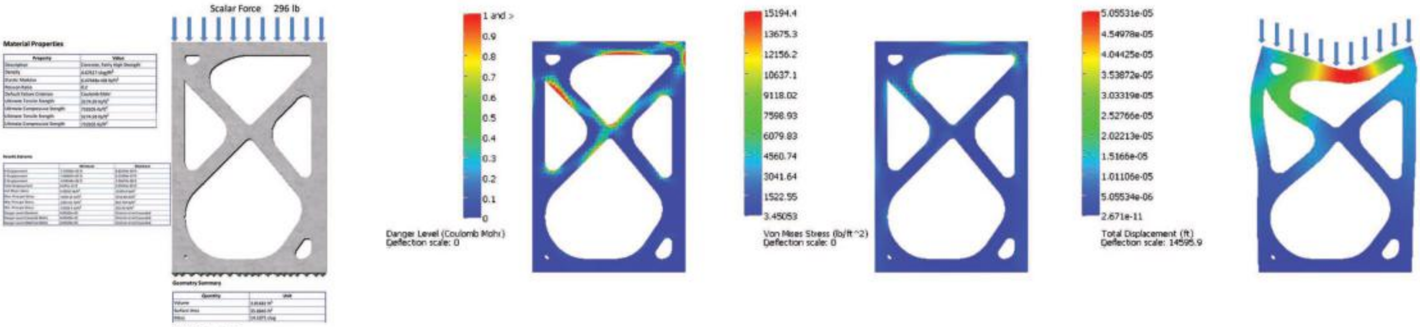
PANEL: J-3



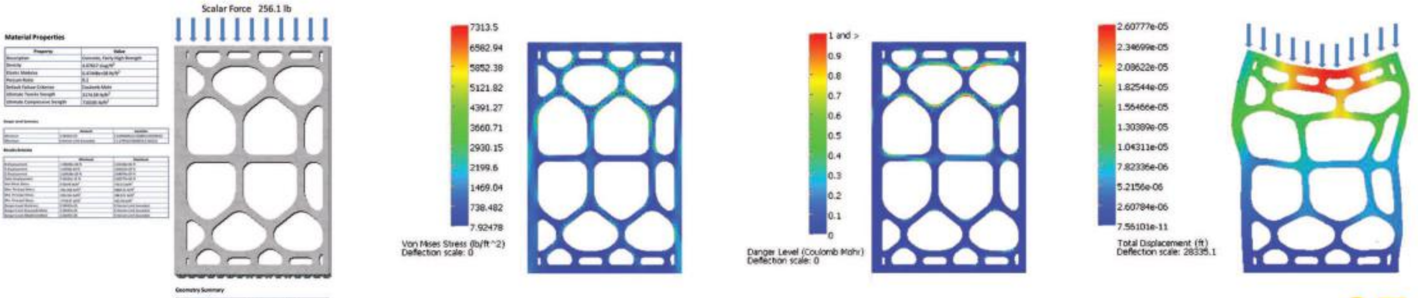
PANEL: F-1



PANEL: I-3

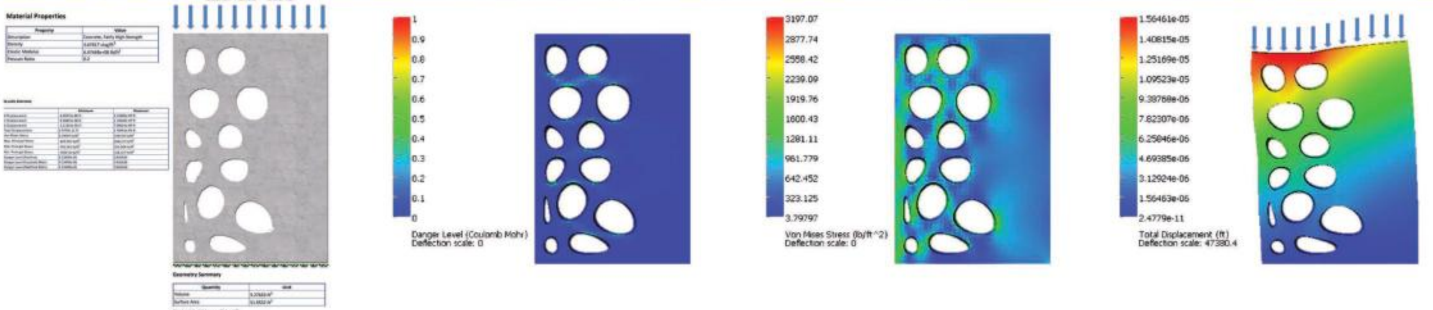


PANEL: J-1

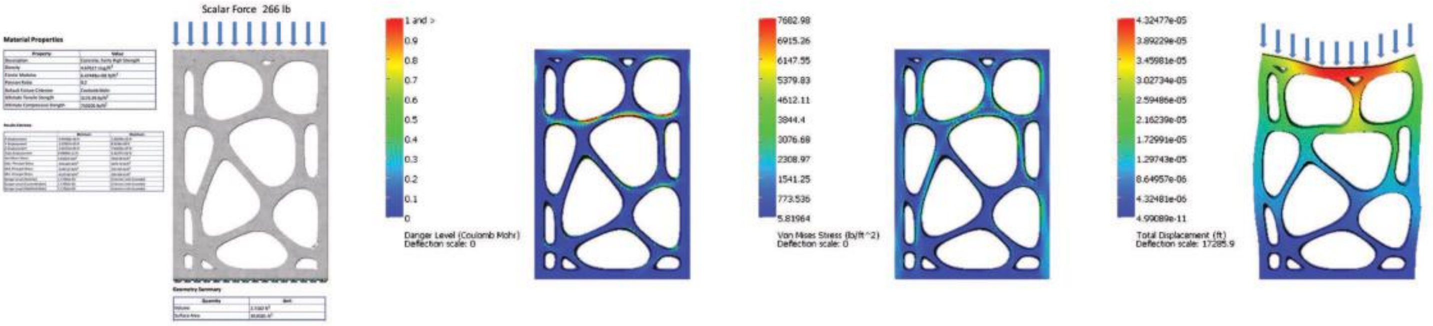


PANEL: H-2

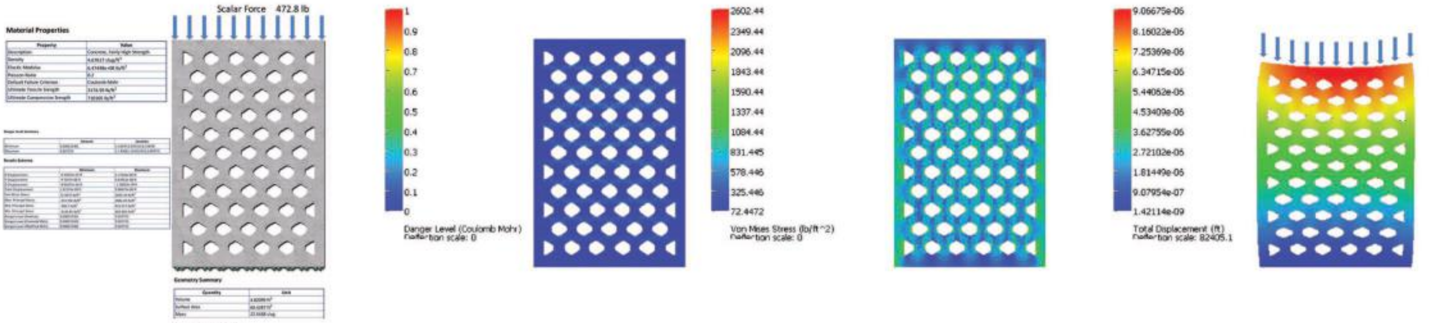
Structural analysis



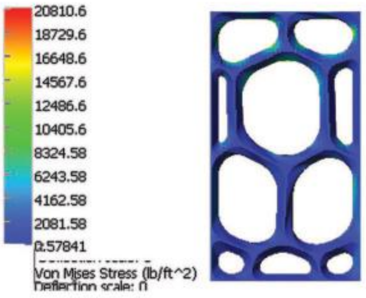
PANEL: D-2

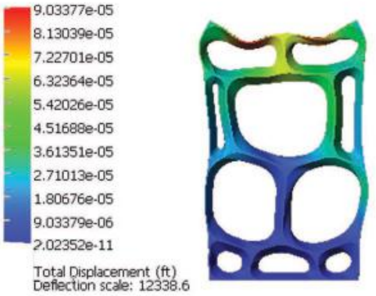


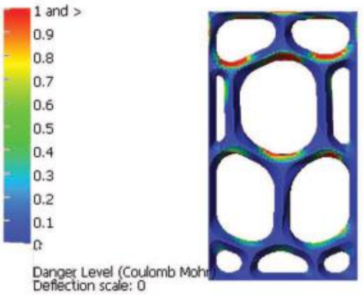
PANEL: H-3



PANEL: C-1



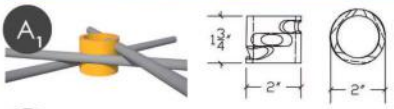


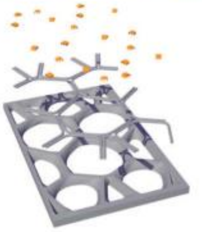


STRUCTURAL ANALYSIS TOOK INTO CONSIDERATION ON THE SELF WEIGHT OF THE CONCRETE PANEL AND WHERE THE STRESSES WOULD BE DISTRIBUTED TRHOUGH OUT THE PANEL. THIS INFORMATION WOULD THEN BETAKEN INTO CONSIDERATION FOR THE ORDERING AND PLACEMENT OF REINFORCING BARS TO BETTER ACCOMODATE THE TENSILE STRESSES AROUND OPENINGS IN EACH PANEL TYPOLOGY

FINAL PANEL

clip design



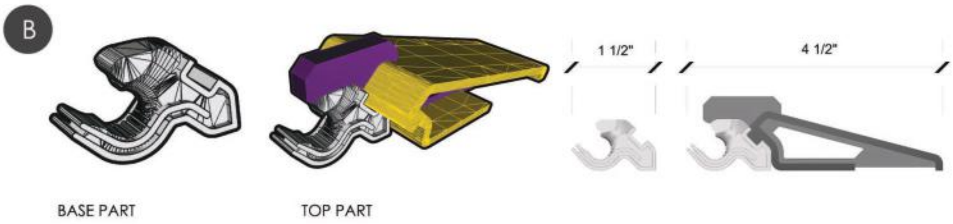


MULTI-PURPOSE REBAR BENDING CLIP

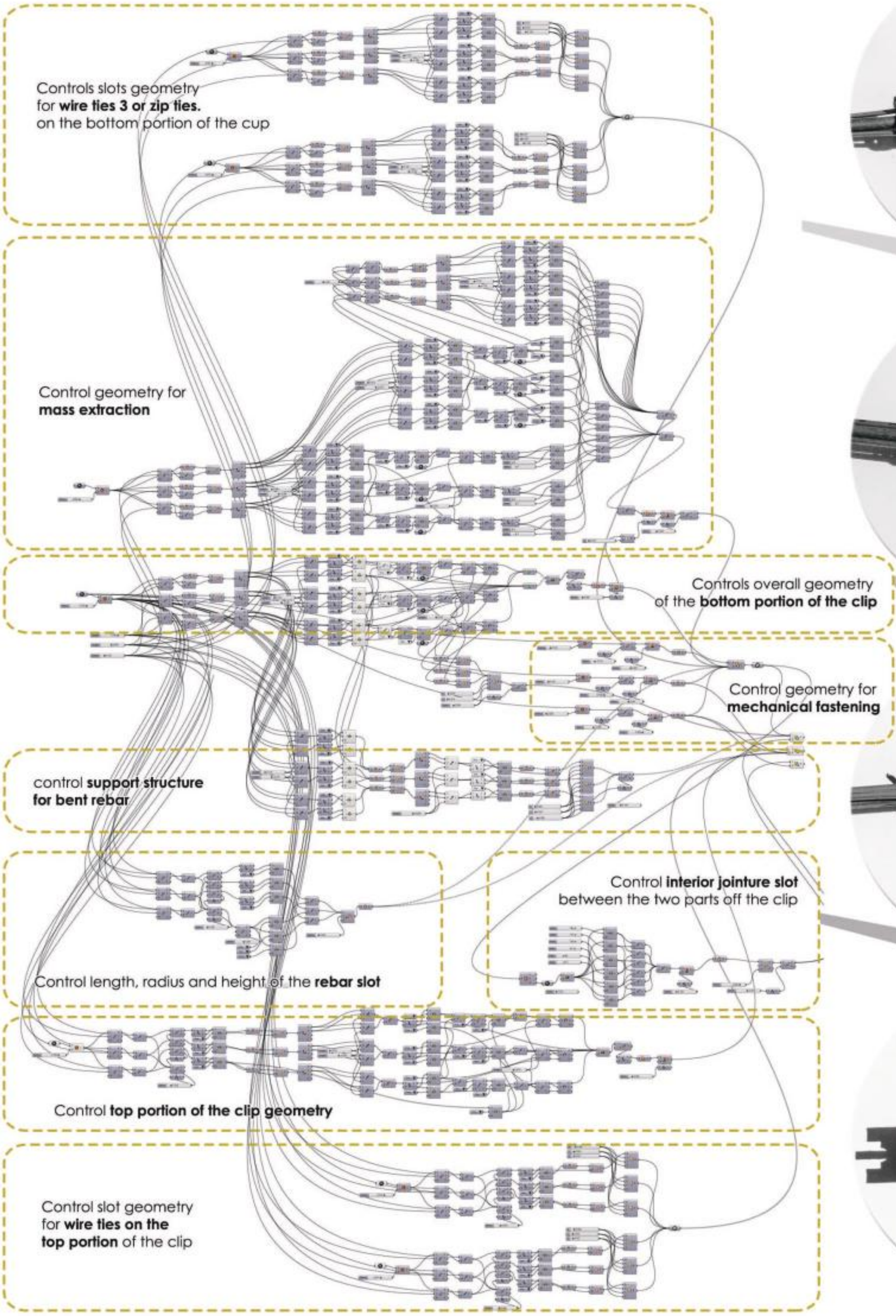
Clip design ultilize its geometries not only bend rebar into its designed form but also allow placement and positioning of rebar ordering when it comes to placing concrete in a reinforced panels.

Clip advantages over existing marketed clips is that it allow omni directional ordering of rebar ordering as oppose to the traditional perpendicular and parallel ordering system.

Result:
Physical testing proved that this proposed clip did not accomplished in bending the rebar effectively while there is more effficient way to bend rebar in the market.



CLIP DEFINITION DEVELOPMENT



Controls slots geometry for **wire ties 3 or zip ties.** on the bottom portion of the cup

Control geometry for **mass extraction**

Controls overall geometry of the **bottom portion of the clip**

Control geometry for **mechanical fastening**

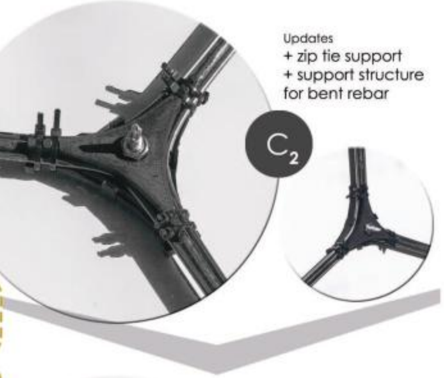
control **support structure for bent rebar**

Control **interior jointure slot** between the two parts off the clip

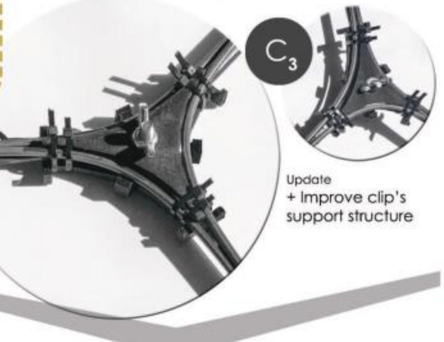
Control length, radius and height of the **rebar slot**

Control **top portion of the clip geometry**

Control slot geometry for **wire ties on the top portion** of the clip



Updates
+ zip tie support
+ support structure for bent rebar



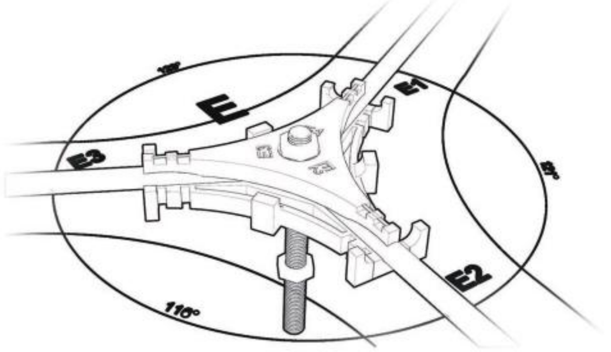
Update
+ Improve clip's support structure

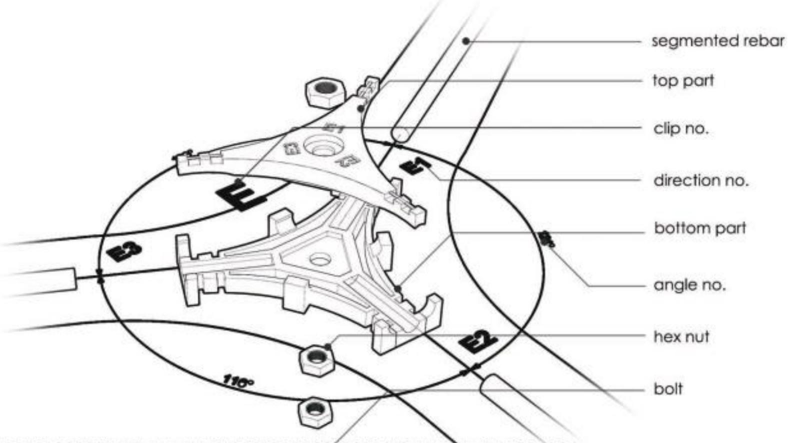
Updates
+ numbering system

fabrication process

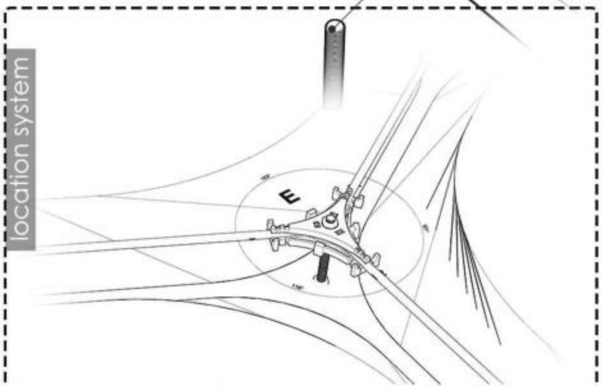
MAIN PROCESS

clip

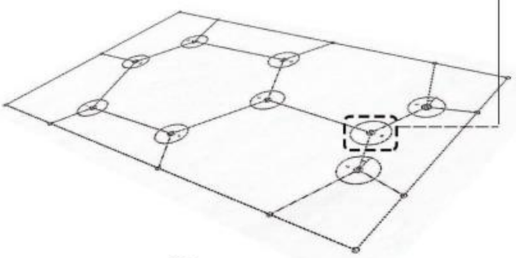




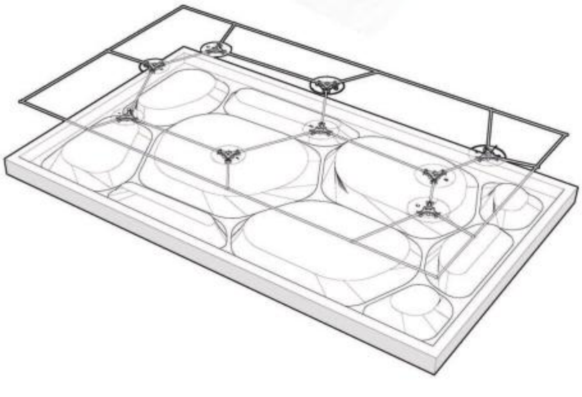
location system



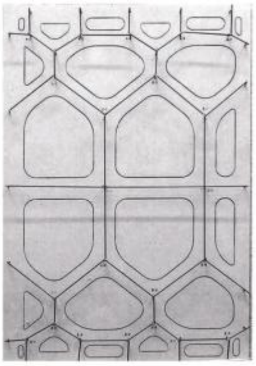
location map



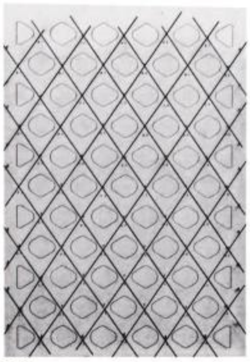
mold



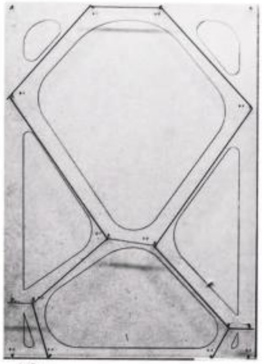
REBAR LAYOUT DIAGRAM



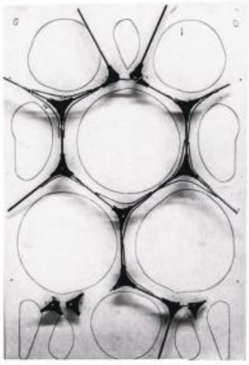
H2



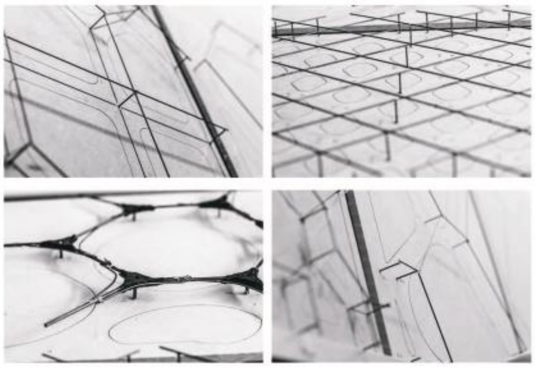
C3



J2



J3



SUPPORTING PROCESS:

CUT

SAND

BEND

MIXTURE PREPARATION

	MATERIAL NAME	PERCENT (%)	WEIGHT (lbs)
01	WHITE PORTLAND CEMENT	45	125.45
02	WHITE QUART SAND	11	30.66
03	3/8 LIMESTONE	17.91	49.93
04	LIME POWDER	4.8	13.38
05	METAKAOLIN OPTIPAZ	2.8	7.8
06	POROVAR 0.1-0.3	8.55	23.83
07	POROVAR 0.25-0.5	6.35	17.7
08	POROVAR 0.5-1.0	3.25	9.06
09	SUPERSIZER 7 PLASTER SIZER	0.32	0.892
10	GRACE MICRO FIBER P.P FIBER	0.02	0.05
	TOTAL	100	278.752
	WATER		80.64

MATERIAL WEIGHT PER VOLUME : **98.5** IBS PER FEET^3 (COMPARED WITH **150** IBS PER FEET^3 OF NORMAL CONC.)