PLAYING OUT THE PATTERN

ROGER HUBELI
Syracuse University

JULIE LARSEN
Syracuse University

With the Oxford dictionary definition of PATTERN as "an intelligible form or sequence discernible in the way in which it is done," 'playing out' begins at how to use patterning to explore the perceivable performance and formal attributes of a material. Using advanced, high-strength concrete materials for the design of a pavilion; the final form rebukes the traditional 'rules' of concrete that it is a heavy and thick material. The pavilion is conceived as extremely light and mobile with a poche that becomes thin, punctured, and seemingly transparent, formed by only two inch thin structural walls. The formal twist of patterns that is used to achieve these attributes reveals the complexity of the performance of a material that wants to generate a completely new understanding of what surface, structure and form can become. Deleuze and Guattari describe this more playful methodology as similar to the Gothic approach of constructing where 'the static relation, form-matter, tends to fade into the background in favor of a dynamic relation, material-forces.'[1]

Sheila Kennedy's argument in Material Misuse that, 'the perception of qualities attributed to materials, and our multiple understandings of what it means to be material, are all integral parts of media culture,'[2] was the departure for investigating prototypes through digital patterns and typology. Patterns merged the formal expressions of the cross-vaults with the performative needs of mobility for each element. The pattern of voids comprising the concrete surfaces served three purposes to change the perception of the material.

First, the pattern of voids aimed to make the form appear spatially light with punctures comprising more than fifty percent of the surface. Second, the patterns of voids aimed to reduce the actual weight of the pavilion. And third, patterns were optimized to define the location of voids on the surface so it could maintain as a thin of a surface as possible while still being structural. The paper aims to use three concrete prototypes that materialize the patterns: Punch Card, Baggy Pants, and Wax on / Wax Off method, to show how the design was tested and retested at the scale of digital and analog prototypes to enhance the form, space, and performance of the pavilion. The tinkering with patterns as well as their casting methods translated to multiple iterations of the structural surface to alter the perception of concrete. The paper outlines how through this playful approach, a pattern emerged through continuously playing out the physical test against the digital form and vice versa.

INTRODUCTION

Given the definition of a pattern as a regular and intelligible form or sequence discernible in the way in which something happens or is done, the design uses the study of patterns to explore perceivable relationships between intelligible form and discernible performance of a material. In the narrative for a finished design each pattern prototype was seen as an iterative step towards one optimal intelligible form of the pattern. Deleuze and Guattari describe this as a Gothic approach where 'the static relation, form-matter, tends to fade into the background in favor of a dynamic relation, material-forces'. Each pattern produced its own formal logic that then was tested out in a digital model for the entire pavilion.

The objective of the pattern was to show the potential in using advanced concrete mixes for the design of transparent and light structures; rebuking the perception of concrete as a heavy, and opaque material. Sheila Kennedy's argument in Material Misuse that, 'the perception of qualities attributed to materials, and our multiple understandings of what it means to be material, are all integral parts of media culture,' was the departure for investigating the concrete prototypes through digital patterns. Once the pattern was manifest as a digital form, the material was no longer 'present' as a texture map of concrete but inherently embedded in the form due to the form deriving from making with the actual material.

BACKGROUND

The design and fabrication of the 10'x10'x10' pavilion consists of only three different types of modules to comprise of sixteen mobile elements. The goals were to use metrics and optimization of a pattern to comprise surfaces that alters the aesthetics of modern concrete as a thin form. Because the fiber reinforced concrete mixture has the capacity to make extremely thin casts, the elements were made with only ½ inch thick walls. For any scale and height, ½" thickness, without traditional steel but fiber reinforcement, is an achievement because of its ability to maintain high structural strength despite the high bending forces in the thin cross-section of the walls. This is contrast to thin structural shells where no bending occurs. The high performance concrete is able to reduce the structure to thin, half inch surfaces and create hollowed-out column elements that would otherwise not be achievable with traditional concrete. The transparency of the elements, due to the pattern of voids, provide a sense of lightness, a profound departure from preconceived notions of what concrete typically represents.

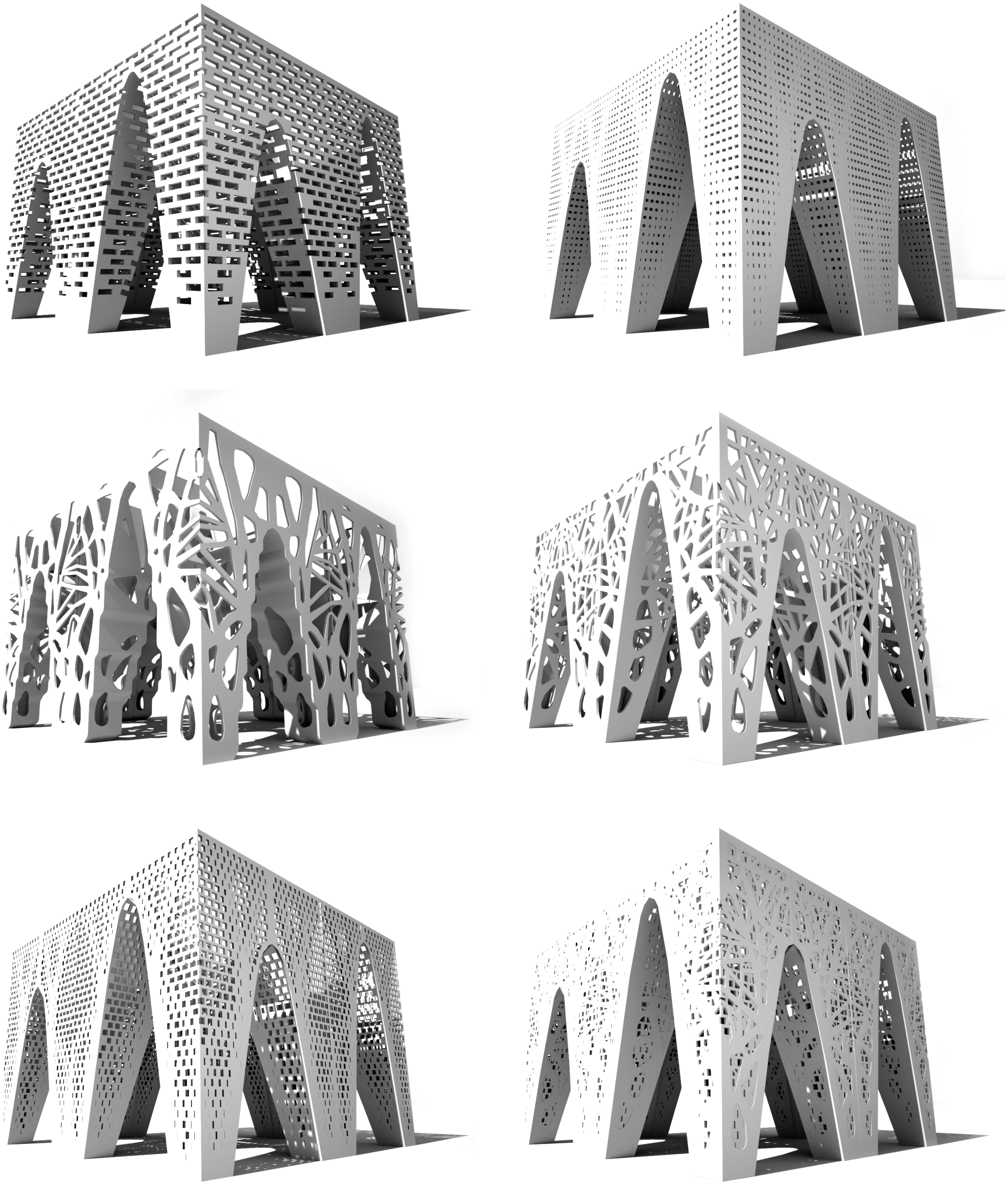

Figure 1: Details of different patterns in digital models. Lower left form was the final form based on formwork prototypes. (Renderings by author.)

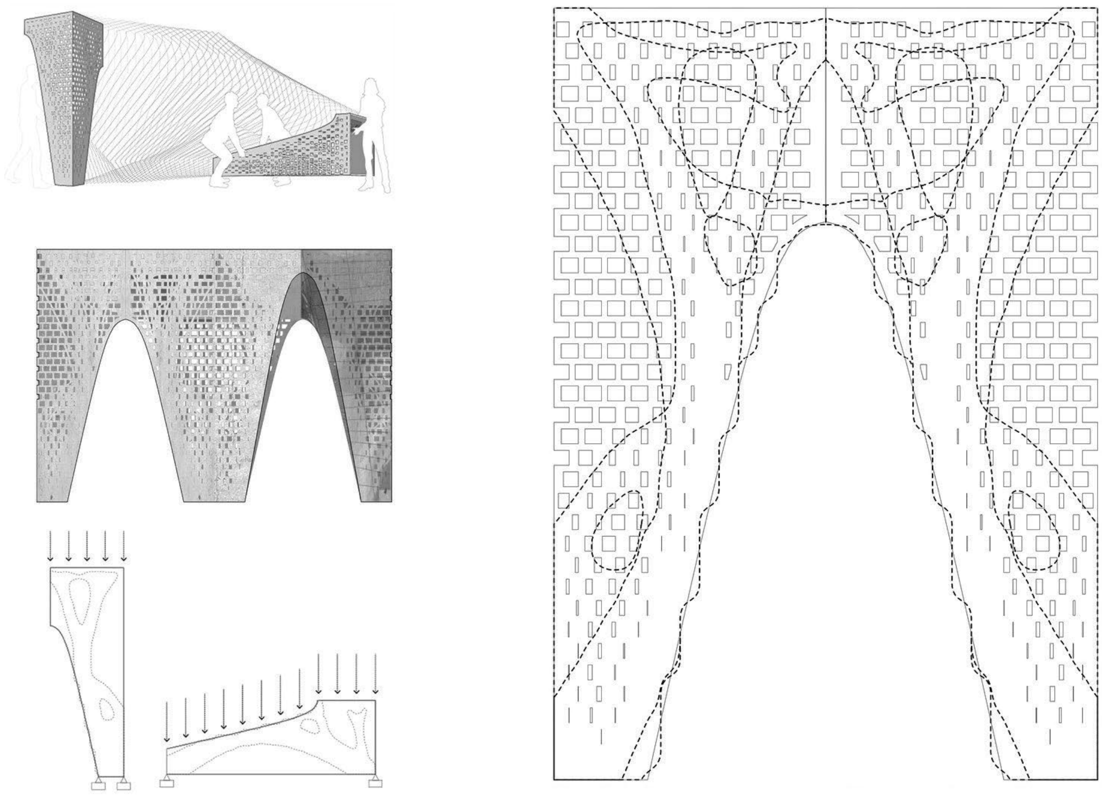

Figure 2: Left: a. Movement of mobile elements, b. SAP2000 overlay on one column element, c. stress and load distribution in horizontal and vertical position, Right: Digital pattern overlapped with bending and shear stresses on the elements. (Diagram by author.)

To explore the innovative potential of a material, the following design methods aimed to achieve a formal quality with the thin vaults with the use of high performance lightweight concrete and patterning to determine the transparent quality of the surface and space inside. The following fabrication methods aimed to alter a cross-vault topology, construction logic, and preconceived understandings of the aesthetics of concrete. Through the use 'pattern play,' or various changes to the pattern of the voids, the pavilion is taken beyond an abstract form and is studied at the scale of seams, edges, and surface texture as well as connections, weight distribution, and structural performance of a surface to create a more tectonic expression.

ITERATIVE PATTERNS OF VOIDS

The aspirations of the patterns were to intertwine the formal expression of the cross-vaults with the performative needs of mobility for each element. This established that the pattern of voids must serve two purposes simultaneously; appearing to make the concrete surfaces look spatially light and actually making the weight of the elements lighter with reduction of material due to the voids. To test the form and performance of different patterns, prototypes were developed through a study in computational patterns in grasshopper, the formwork and casting methods that were then translated to a digital model for the form of the overall pavilion. Three design strategies, each relating to a pattern prototype for the formwork strategy were developed: Punch Card, Baggy Pants, and Wax on / Wax off. The following descriptions outline the physical prototype of the patterns and the resulting digital form of the patterns. The third prototype was used for the final casting of the pavilion.

THE DIGITAL PATTERN

Using a computation technique in grasshopper, 'diffusion limited aggregation,' digital models of the individual elements and the overall form were studied to determine optimal surface patterning on the exterior and interior elevation (Figure 1). The high performance concrete already weighs less than half the normal weight of concrete but the voids reduced the weight of the elements to almost a quarter of typical concrete. Due to the voids, the reduction of the weight, brings more spatial quality to the inside by creating a lighter, more open surface.

Since the elements are mobile to accentuate their lightness, a structural analysis tested the highest stresses located on the surface of each element as they are carried from an upright to a horizontal position. To emphasize the surfaces held the strength, the pattern made in grasshopper on the skin,

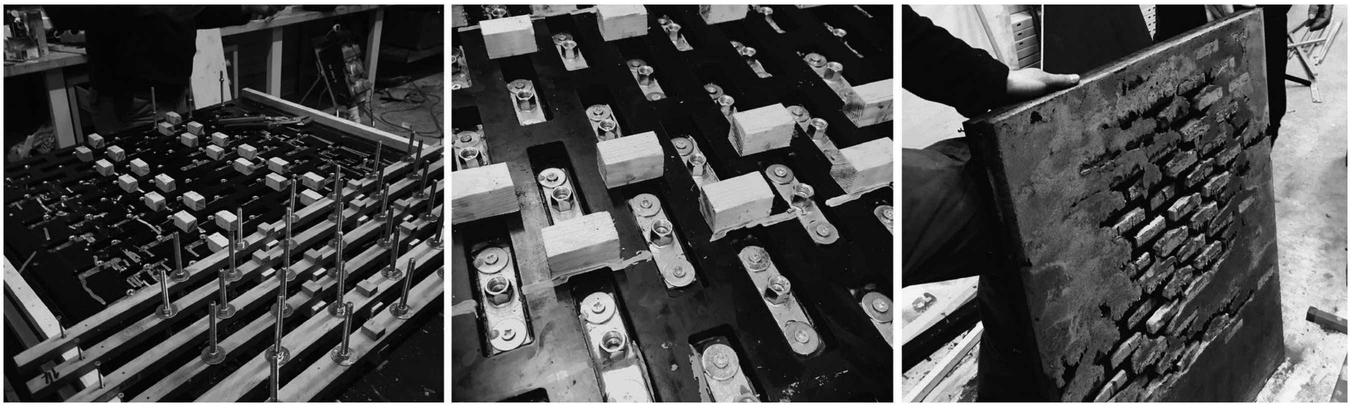

Figure 3: Punch Card method was not easy to demold, resulting in most of the wood staying in the cast. (Photographs by author.)

responds to the overlapped stress and load patterns for the horizontal and vertical position of the element. Where stress on the surface is higher, the voids are reduced to allow for more cross-sectional area (Figure 2, left).

STRUCTURING THE PATTERN

Structural modeling (SAP 2000) was used to determine optimal locations of the pattern of voids based on the bending moment and shear stresses. This method allows for a pattern to be optimized according to the occurring stresses, similar to the facade of Steven Holl's Simmon's Hall at MIT[3]. To determine where voids could be eliminated, the 'diffusion limited aggregation' technique was altered to matched the structural diagram. The arc of the structural diagram, informed where the pattern in grasshopper, became denser to ensure a proper load distribution (Figure 2, right). This showcased the concrete's capacity to become more transparent and to emphasize that the shell of the elements were both structure and skin. Facade pattern studies tested the limits of the wall thickness in relation to the voids in the surface. With this method, multiple iterations of the void to mass ratio was recalibrated to examine the limits of the mix in relation to the desired design of the forms.

PATTERN VERSUS MATERIALITY

The matrix of the mix, the additives, as well as the fiber reinforcement were continuously adapted to the form and the computational input for the pattern on the surface of each column. This created a feedback loop for both the design of the form as well as the design of the concrete. Choosing the final pattern was a question of composition as well as finding an appropriate scale for the voids in the surfaces. The final scale of the voids were not ideal for the concrete mix because the mix required 17 mm long steel fibers yet the mass between voids in the surface were only 15mm wide. This resulted in CEMEX reducing the steel fibers to 15mm in length and adjustments to the flow of the mix in order for fibers to easily move through the formwork. Reduction of the fibers from 17mm to 15mm in length had not been attempted with the CEMEX team prior to the project, which was an accomplishment to achieve such thinness and maintain structural strength.

PROTOTYPE I: PUNCH CARD

With the intentions to create a light structure, the first formwork attempt, Punch Card, used rectangular voids as a repetitive element throughout the pavilion, referencing the walls of Rietveld's Pavilion at the Kröller-Müller Museum. To create the most flexibility to arrange the voids, a 'punch-card' formwork was constructed out of a matrix of pegs. The pegs were held with screws in a larger frame of the formwork with screws changing the vertical position of each peg. The ability to change the height of the pegs allowed for 're-programming' of the pattern for each cast. This meant that varying patterns could be punched with voids or with deep and shallow indents (Figure 3).

The amount of pegs and open-endedness of their vertical positions required substantial effort to re-program the formwork for each pour; thus needing to adjust dozens of screws when going from one design pattern to the next (Figure 3, middle). This was a significant effort that was disproportionate to the small scale of the pavilion. In addition the large number of pegs made the formwork malfunction easily, leaving inconsistent qualities of casts and challenging to demold.

The digital model reveals that one physical prototype can result in many varied patterns to achieve different formal expressions at the scale of the pavilion. The larger voids of the rendering on the left dematerialize the form because the underlying grid hinders the pattern to adjust freely to disruptions, such as arches, in the facade. While the varied and smaller voids of the rendering on the right holds the original formal logic of the arches. In both cases, the holes had little change in form, resulting in a more rigid expression that was too subservient to the method of the formwork rather than the complexity of the project.

PROTOTYPE II: BAGGY PANTS

Inspired by the fabric casts of Mark West at C.A.S.T.[4] voids were welded into a transparent plastic bag and draped on a wood scaffolding. The transparency would allow for visible control of the mix during casting. To assure proper sealing of edges, the voids were rounded and the corners were draped around the edge of the wood formwork (Figure 4).

The cast proved that the welding of the voids into the plastic and controlling the flow of the mix in the formwork would be relatively easy. On the other hand, it was hard to reduce the size of the voids while maintaining a continuous distribution of the material in the formwork. In addition, the formwork could not be adapted to create variations to the voids. The resulting form of the prototype was imprecise due to the creasing of the plastic (Figure 4, lower right).

Extrapolated to the form of the entire pavilion, the voids of the Baggy Pants prototype were imagined as a skeleton-like structure, with the pattern creating a formally complex geometry that competes with the archways. The skeleton in the rendering on the left, dissolves the archway with large voids and rippling in two axis that make it visually complex to read the original figure of the pavilion. The skeleton in the rendering on the right has smaller voids but the resulting geometry is still in competition with the geometry of the arches.

PROTOTYPE III: WAX ON / WAX OFF

The final approach used a prehistoric technique of 'lost wax molds' and casting method where a wax formwork is melted and reused after each cast. The lost wax method is achieved through the use of waterjet cut silicon inlays in steel formwork that are cast with wax and then removed. The remaining wax served as a formwork to cast the inverse form in concrete. The wax was melted away after the concrete was cured and re-used for all subsequent pours and casting of the remaining elements. This method was very beneficial to precisely making a complex geometry with small-scale voids in the surface because the wax cast can be precise and easily demolded. The lost wax prototypes showed that the method was achievable when both the wax didn't shrink and the concrete mix was fluid enough to evenly fill the formwork. Referring to Gramazio Kohler's high efficiency concrete wax mold system Harry Gugger argues that a wax formwork method is ideal for the production of complex geometries where "concrete molds [are] difficult to manufacture" and the molds produce "a large volume of waste, but this approach solves both problems."[5]

This final formwork used for the pavilion was a combination of new digital fabrication techniques, with water jet cut welded steel forms and water jet cut silicone inlays. These were used alongside the wax molds. Since the silicon inlays could be used to generate different wax forms in the same steel formwork, the combination of these different techniques created complex patterns with a minimal amount of steel formwork. The columns of wax were poured and then the silicon was peeled away to reveal the wax columns. The

Figure 4: Casting Method of Baggy Pants. Upper Left: welded plastic formwork, Upper Right: concrete cast on one side, Lower Left: cast of corner, Lower Right: demolded cast. (Photographs by author.)

wax inverse columns were self-supporting before adding the steel formwork back to encapsulate the wax molds. Once the steel exterior was back in position, each column of wax was melted away with long tube heaters running the length of the columns. The steel formwork was removed with only the concrete column remaining.

One additional steel formwork was used for the fabrication of the four middle skylight elements that become the interior skylights. They are fabricated without patterns but with the same ½" wall thickness. The skylight elements are held in place by the ring of the 12 modular columns and bring light and lightness to the center space.

RESULTS

The first two methods, the Punch Card and Baggy Pants formwork, revealed the weaknesses in both casting methods that did not result in a formal logic that could be changed easily or controlled in terms of the surface quality and precise location of the voids. The digital pattern needed to overlap with the stress and load distribution in the horizontal and vertical position of the elements to ensure there was enough material where stresses were high. To determine where to place voids, according to the structural analysis, only the lost wax fabrication method of 'wax on / wax off' was successful in being able to precisely control the location of the voids. The first two techniques rendered inconsistent results of void location, size, and thickness of spacing between voids, which could result in surface failure once the pieces are moved or

Final casting process of 'wax on / wax off' method with, a. peeling away silicon inlay once wax is cast, b. final wax formwork prior to casting the concrete, c. final columns with pattern as void (Photographs by author).

rotated. In the final 'wax on /wax off' technique, both the digital pattern and the lost wax formwork was the most precise in executing the desired pattern. Thus, the final pattern was a fusion of both form and performance of the pieces to reinforce their lightness and mobility.

In addition, the 'wax on / wax off' method did not sacrifice composition, surface quality and edges of the form. The chosen pattern created a density of voids where we needed less material and less voids where we needed more material. This change in number of voids was accentuated and traced the structural stress patterns to create a more varied surface around the entire pavilion. The final design gives a sense of lightness and transparency while maintaining the the structural performance embedded in the surfaces and the integrity of the form and arches of the vaults.

CONCLUSION

Through digital and physical prototyping, a series of patterns emerge[6] that challenge the understanding how how concrete can be precieved. Rather than building prototypes to find the best way to construct a premeditated form or to refine a method of fabrication; the prototypes themselves become an inherent part of the formal development of concrete forms. And this is the basis for uncovering the relationship between 'playing' with digital patterns, concrete materials, and fabrication methods to discover intelligible forms that are discernible by the way in which they are made. Prototyping leads back to Guattari's belief that form is not statically connected to matter but the relationship between pattern, overall form, and material emerges with each new prototype. By challenging the structural logic of the cross-vault of the pavilion, through strengthening the capacity of its skin, a new aesthetic emerged for modern concrete as a thin form, rather than a thick poche. 'Playing out' a formal technique through iteration of different digital patterns that are 'played out' against various fabrication techniques is a unique methodology to find new aethetic and formal potentials with new materials.

ENDNOTES

1. Deleuze, Gilles, and Felix Guattari. *A Thousand Plateaus: Capitalism and Schizophrenia*. London/New York: Continuum, 2004. 401-402.
2. Grunenberg, Christoph, and Sheila Kennedy. "Material Presence." *Material Misuse: Kennedy & Violich Architecture*, Architectural Association, 2001, p. 5.
3. For a more detailed description of the structure of the facade see: Nordenson, Guy. 2016. *Guy Nordenson: reading structures* : 39 projects and built works, 1983-2011.
4. For a recent overview of his work see: West, Mark. 2017. *The Fabric Formwork Book: Methods for Building New Architectural and Structural Forms in Concrete*.
5. Lafarge Holcim Foundation for Sustainable Construction, info@lafargeholcim-foundation.org. "Swiss Researchers Win Global Award." LafargeHolcim Foundation Website, 30 Aug. 2012, www.lafargeholcim-foundation.org/Article/swiss-researchers-win-global-award-for-materials-saving-technolo
6. The term is based on Klaus-Dieter Sedlacek description of the general properties of emergence in: Sedlacek, Klaus-Dieter. 2010. Emergenz: Strukturen der Selbstorganisation in Natur und Technik : Arbeits- und Handbuch. Norderstedt: Books on Demand.