SMOCKING: Pleated Surfaces and Fabric Formwork

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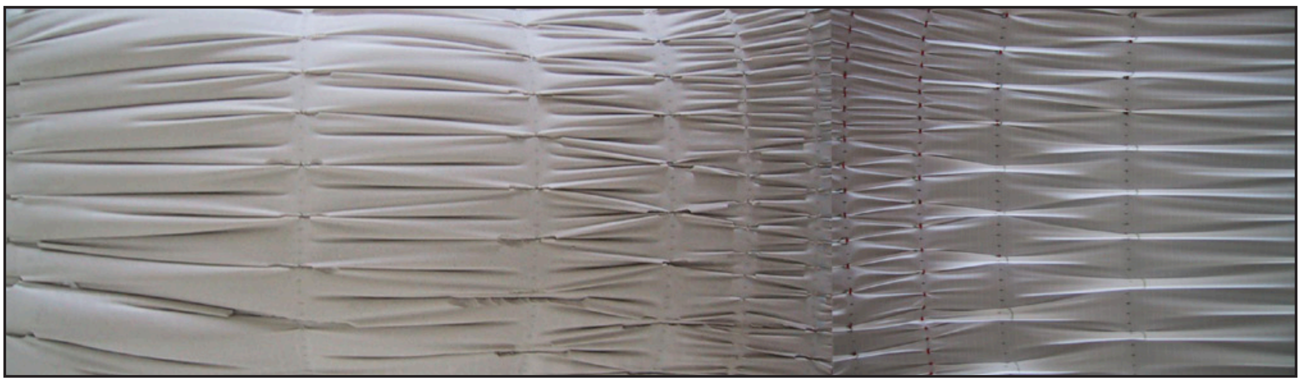

Figure 1: Smocking Version 5 (composite photo of the cast and fabric formwork)

INTRODUCTION

Concrete is a high-strength, low maintenance and versatile material ideal for building construction. The ability to economically reproduce complex shapes that are defined by the formwork is well exploited as precast architectural decorative products, often guised as more expensive and labor-intensive materials.

Fabric formwork technique being studied by Mark West et al. and realized in such products as "Fast-foot" by the Canadian company Fab-form Industries is known to be the most efficient structural use of material for a formwork. Resisting only in tension, fabric redistributes the hydrostatic forces equally in all directions, rigidifying the formwork and making extra reinforcing unnecessary. Light, inexpensive and easy to manipulate, fabric is also an ideal candidate for molding complex three-dimensional concrete surfaces. The bleeding of the air bubbles and excess moisture through the permeable membrane results in an undulating surface with fine textures and finish. This quality is appreciated. However, it is not necessary explored in a systemic manner in regards to the formal possibilities of the surface geometry.

What kind of unique surface articulation can we derive from the combination between fabric surface and concrete beyond the simple funicular geometry? Casting concrete on fabric formwork is a dynamic process. The surface geometry of the fabric changes as the liquid is poured. How can we document, control and refine the surface geometry and construction of formwork in relation to the actual cast? And finally, what potential application such fabrication method may have beyond the qualitative attractiveness of the surface geometry? This paper touches upon the historical development of cement and concrete use as a building material. It also provides a general overview of fabric formed concrete technique to establish a basis to address aforementioned issues through the author's own investigations and outcomes grown out of a series of experimentation conducted in the studio setting with students.

CEMENT / CONCRETE

> "There is also a kind of powder which from natural causes produces astonishing results. It is found in the neighborhood of Baiae and in the country belonging to the towns round about Mt. Vesuvius. This substance, when mixed with lime and rubble, not only lends strength to buildings of other kinds, but even when piers of it are constructed in the sea, they set hard under water."[1]

The Romans knew the existence of Pozzolana, a natural compound of silica alumina and iron oxide referred to by Vitruvius as the "magical powder." The mixture with lime was the predecessor to Portland cement. The critical difference from the lime mortar is the fact that cement cures and hardens in a hydration process (chemical reaction with water). Lime mortar, commonly used for the masonry work in those days, cures and hardens with the chemical reaction with carbon dioxide in the air. This difference is crucial. A side from the significant difference in strength, lime mortar will never fully cure and harden if used in quantities beyond the thin layers between the stones. However cement, a seemingly promising building material was lost during the medieval period where building technology was ruled by the secretive Masonry guild. It had to wait to be rediscovered by John Smeaton, an engineer in the 18c England. He was in quest for a perfect mortar with hydraulic properties suitable for the construction of a lighthouse, an essential infrastructure for commerce in the era of the industrial revolution.

Early studies of cement were focused on improving the quality of mortar for masonry work. However, the hydraulic properties of cement did not go unnoticed. Use of cement as concrete (mixture with sand and crushed rocks as an aggregate) increased as it was recognized advantageous for foundation work on harbors and bridges. As the mechanical understanding of the iron reinforcing progressed, concrete made its way above ground to be used as a construction material for floors, beams and columns. Simultaneously, attempts were made to exploit the property to replicate multiple elements with intricate surface articulations from a single formwork as precast finish components. William Henry Lascelles patented a building system in the late 19c based on precast concrete panels as a way to mass-produce inexpensive houses.[2] The precast panels were fastened directly to regular wood stud framing on both sides as well as onto the roof framing. The efforts were made to replicate the texture and profile of commonly accepted materials and building features. Exterior and interior walls were patterned as wood paneling and the roof in a fish scale pattern of shingles. More famous example is that of the inventor, Thomas Edison's attempt to cast a French-style traditional house in a single pour, including all the decorative profiles, textures and colors.[3] Even to this day, the most common use of architectural precast product is to mimic stone, or brick not necessary to express the nature of the material itself.

Corbusier was the first to esthetically qualify the unique property of concrete to preserve the forms and textures of other materials. He called it "Béton brut," a residual memory of the construction process. The rawness of the concrete, the imprint of the formwork, tie marks and imperfections, were celebrated in projects such as Unite de Habitation. Conversely, the perfect uniform concrete surfaces of Ando's buildings are antithesis to that of Corbusier. It is about complete erasure of rawness aimed at distilling the materiality to its essence, or in his words, "beyond the will of the material."[4] His care to locate tie marks and control joints for the sake of uniformity is legendary. The craftsmanship he demands of his formwork, assuring the smoothness and flatness is baroque contrary to its solemn and subdued expression of the result. "Smocking" falls somewhere in-between the two extremes. It captures the material essence of the liquid working in the gravitational field against the continuous tension surface of fabric, augmented by the human will.

CONCRETE / FABRIC

Fabric formwork is an emerging area of studies in the field of architecture. Mark West, director of the Center for Architectural Structures and Technology (C.A.S.T.) at the University of Manitoba, is the leading expert. His introduction literature for C.A.S.T.[5] notes that the first practical application emerged in the field of geo-textile as an erosion control device. The unsettling scale and the beauty of these infrastructures is one of the prime subjects of the internationally known photographer, Toshio Shibata.[6] Spanish architect Miguel Fisac, known for his precast post-tension concrete structures inspired by the section geometry of bone structure, also experimented with thin plastic sheets to cast textured concrete wall panels in the 70's.[7] In the 80's and 90's fabric formwork technique to cast above ground architectural elements were independently discovered and applied to a full scale construction by three individuals, Kenzo Unno, an architect / contractor in Tokyo, Japan, Rick Fearn, a builder / businessman in Canada and professor West.

Unno's fabric-forming technique is specifically calibrated for cast-in-place concrete walls in residential scale. He has built a number of residences using this method. It has evolved into an extremely efficient building system. It integrates the rigid foam insulation to one side of the fabric formwork, allowing the opposite surface with the beautifully undulating concrete finish to perform as a thermal mass.[8] This is not possible with the typical rigid insulation formwork requiring insulation on the both sides.

Fearn's company, Fab-form Industries in Surrey BC produces fabric-based forms for columns, foundation walls and footings. These products are distributed in Canada as well as in the US. Low cost and lightweight, requiring minimum labor and materials producing less waste compare to traditional formwork using plywood, efforts are made to educate and market to the segments conscientious of building green.[9]

West is the father figure in this emerging field. As a director of C.A.S.T., the first institution focused on the research and education of fabric formwork methods, he is responsible for many of the original inventions and recent innovations. His fabric formed concrete work first appeared on the national scene at the Storefront Art and Architecture gallery in NYC in 1992 as sculptures and drawings in the exhibition, "Pressure Buildings and Blackouts." The intent was to question the role of the traditional rigid geometry we "perceive" and "build" through the indeterminate nature of his "blackout" drawings and the fabric formed sculptures.[10] The exhibition is seminal in defining the qualitative characteristic and the philosophical foundation of his work. Since then, his research has primarily been devoted to the areas of; a) Development of the techniques and methods to apply fabric formed concrete to the architectural scale construction, b) Design of the structurally efficient reinforced concrete beams and trusses using fabric-forming geometry, c) Application of fabric forming principles to other construction methods such as shot-create, rammed earth and masonry brick vaults.

Along with Fearn, West cofounded the International Society of Fabric Forming (ISOFF), an institution dedicated to the communication amongst researchers, professionals and the building industry. Members such as Sandy Lawton of Arrodesign in Waitsfield, Vermont[11] are actively utilizing the fabric-forming concrete technique in all aspects of construction of residential scale structures.

MATERIALITY CAUGHT IN-BETWEEN

The embodied knowledge of making is gained through the physical interaction with materials, searching for an order rooted in history, perception and materiality. The third year design studio taught by the author in spring 2008 was designed to encourage students to develop an innate understanding of relationships between the materiality and logic of construction through the exploration of fabric-formed concrete and its tectonic possibilities.[12] The studio yielded the following results relevant to this paper.

i) In order to qualitatively evaluate the cast and to reflect and improve the design of the next cast, a stationary medium documenting how the formwork is constructed is an absolute necessity.

ii) Conventional pictorial depiction of the end results does not work for the documentation purpose. It must be a precise record of the nature of the manipulation done to the fabric surface as well as the location and sequence. It also needs to project the general formal characteristics of the cast. Documentation method analogues to the tailors' pattern drawings were developed for this purpose.

iii) Pleated surfaces are one of the most qualitatively attractive surface articulations fundamental to the fabric. In conjunction with the funicular geometry, it takes on additional dimensions when they are transferred into the hard surface of concrete.

Following the results, the author focused on the surface articulation technique called "smocking" and conducted scaled fabric forming experiments using Hydro-cal in lieu of concrete. The assumption is that the fabric forming technique is scalable. In other words, if you can fabric-form a cast in a scaled condition reasonable for a single person to perform, it can be accurately transferred to an architectural scale cast with modest effort. This is anecdotally a well-accepted fact by the experts in the field.[13]

Simultaneously, a notational drawing method to document the fabrication and to speculate the alteration was developed.

Following constants (boundary conditions) were established for the experiments:

1) Size of the fabric: 33"x33".

2) Size of the frame: 22-1/2"x10-1/2".

3) Fabric surface was augmented through "picking" points (see Figure 4). No alterations were made by cutting and/or sewing.

4) All notational drawings were done in full scale prior to the fabrication of the formwork.

Following variables were investigated in the initial batch of experimentation:

5) Dimension of the point matrix. This affects the general length and depth of the folds on the fabric formwork.

6) Method of "picking" points: how many points are picked and how (in what pattern) they are picked. What effect does it produce locally? This affects the general characteristics of crease lines around the picking points.

7) Pattern of picking points: the relationships. This affects the general characteristics of how the crease line travels.

SMOCKING

A total of 4 types of fabric forms were constructed and 5 casts were performed within a 4week period in June 2008.

Figure 2: Casts (from left to right v2, v3, v5, v4.1)

Version 1: Test smocking on cotton muslin. No casts were performed on the formwork. The drawing explored the folding depth and length of the pleats, constant 1/2" increments on X direction and variable dimensions based on the golden ratio on Y direction. The fabric was ironed carefully according to the drawing to "record" the folds on the fabric surface. Every two pleats were threaded at midpoints of the folding depth determined by the "eye" and tied together, collapsing the folded fabric surfaces into a single point. Distribution of the "thread points" alternating from row to row remained consistent.

Version 2 (see Figure 2): First cast. Smocking on cotton muslin. The drawing was modified to indicate the threading points (picking points). It reflects the discovery from the previous test that spacing of the picking points automatically establishes the folding depth (see Figure 4.) and remained constant at 1/2". The folding lengths (Y direction) were altered. Line (indicated in blue) speculating the potential creases were introduced between the picked points. However, it is not an accurate representation since the method how points were picked (indicated in red) ignores the fact that they are often picked in multiple pairs. This crucial defect in the notational system is not remedied until the design drawing of Version 5. The cast did not release from the fabric formwork for the following reasons. a) Geometry of the fold at the pick points on the poured side allowed tunneled condition where hydro-cal flowed in.

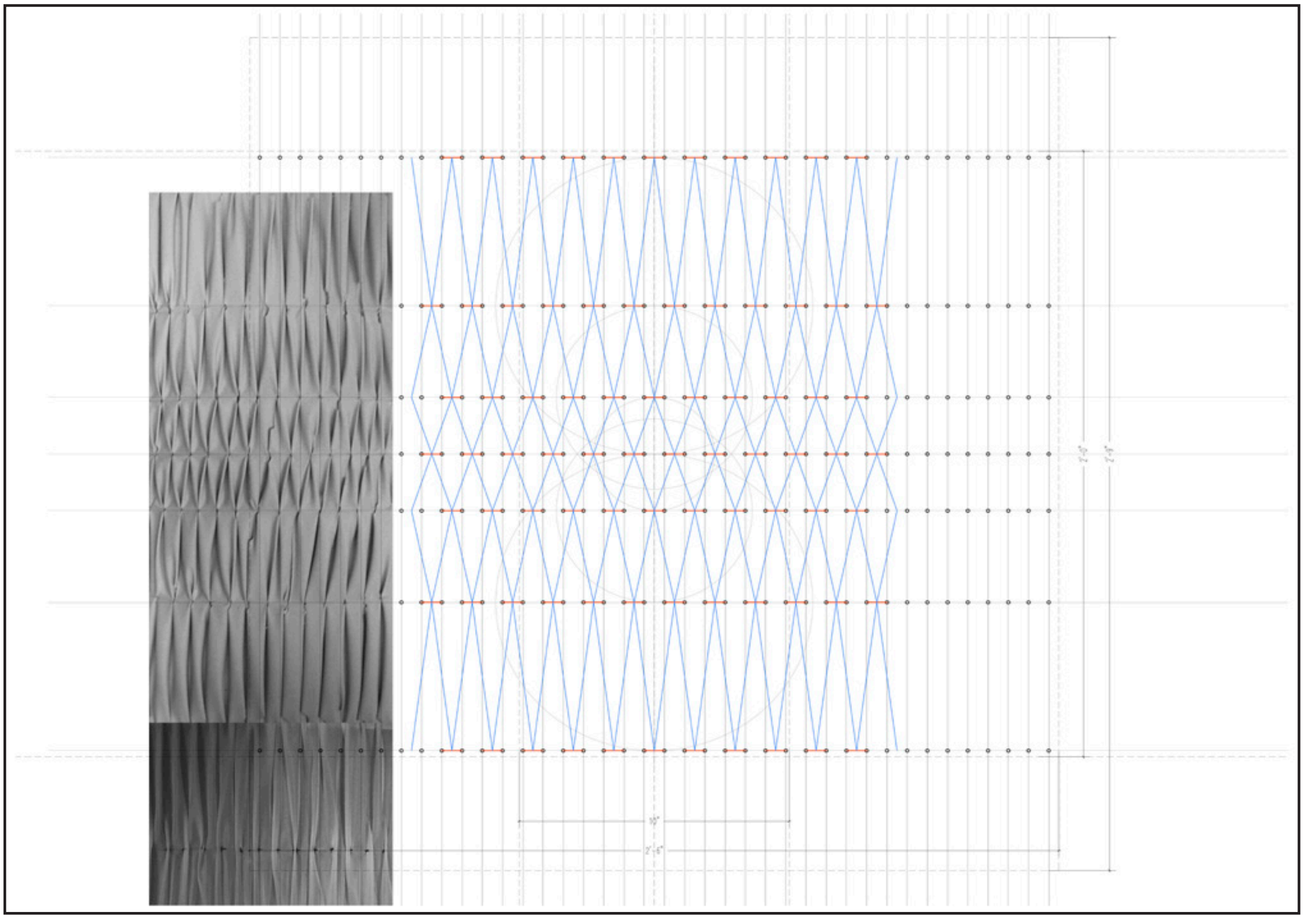

Figure 3: Smocking Version 3 (cast w/ notational drawing)

b) The fabric was caught in the cast due to the deep fold. High friction of cotton muslin made it cumbersome to release the cast from the formwork.

Version 3 (see Figure 3): Second cast. Smocking on nylon flag fabric. In order to resolve the cast release issue, alternate fabric was chosen. Hydro-cal poured on the opposite side of the smocked surface to avoid the material to fill the tunneled condition. Shorter folding length is assigned to the middle section to control the bulging with slightly shorter folding depth at (3/4”). The estimated crease line in the drawing accurately correlates with the cast results. Stiffness of the fabric itself at the given scale affected the surface articulation seen as an inflection in the fold.

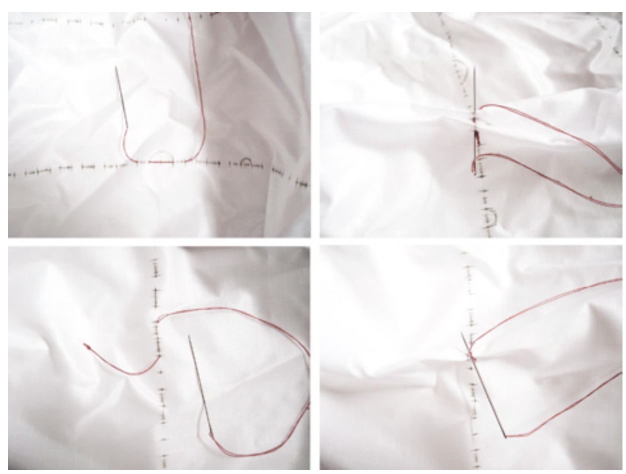

Figure 4: “Picks” (two examples: type A above, type B below)

Version 4 (see Figure 2): Third and forth cast. Smocking on rip-stop nylon fabric, thinner and softer than nylon flag fabric. Formwork was reused for the second cast to check against repeat casting. No

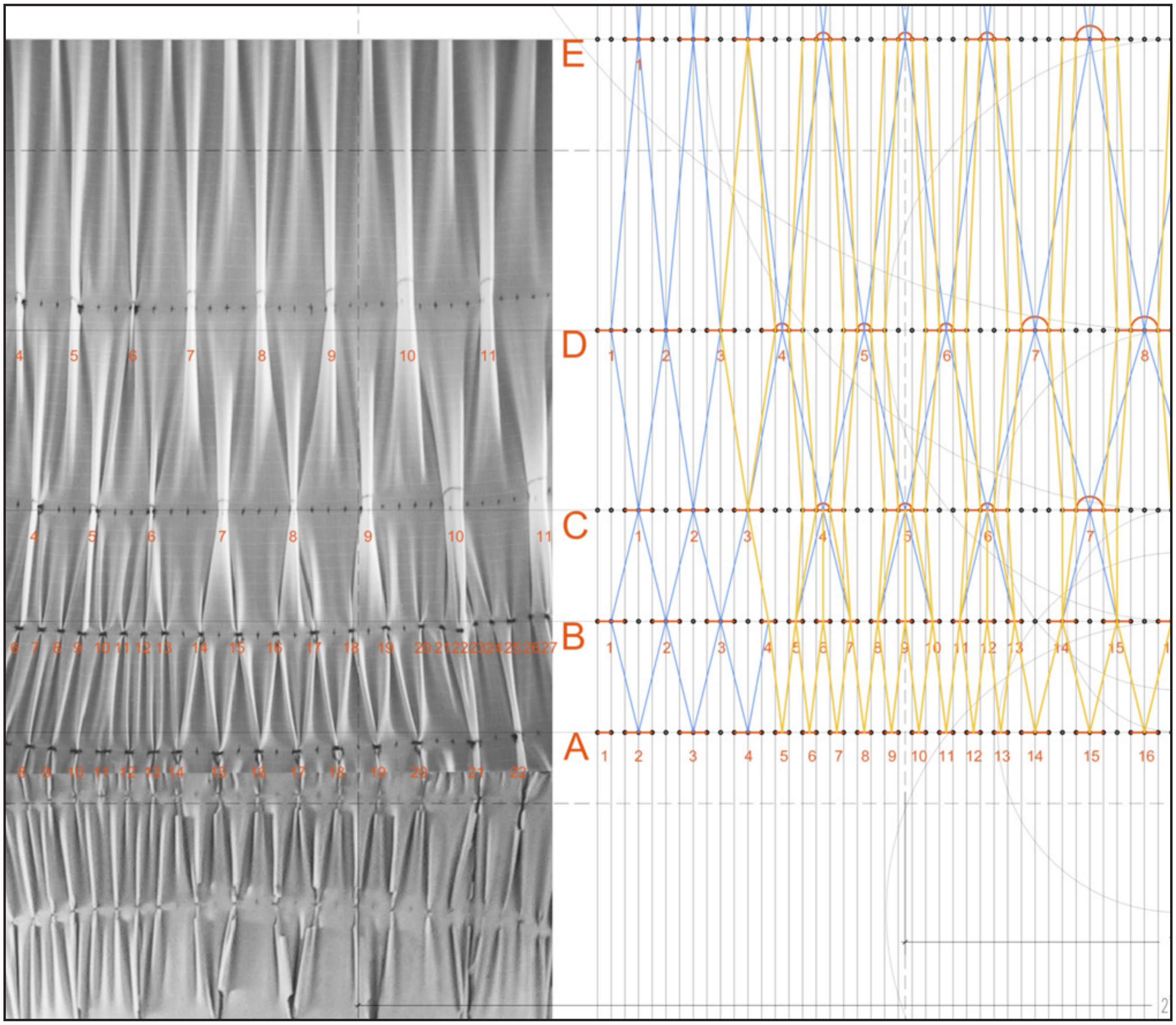

Figure 5: Smocking Version 5 (formwork analysis w/ notational drawing)

dramatic changes were observed in the repeated cast. Folding depth was dramatically shortened to (1/4”) to test how far the crease line will travel. It was observed to be (2”+/-) in the given condition.

Version 5 (see Figure 5): The fifth and the final cast for this batch of experimentation. Base dimensions for the point matrix remained relatively unchanged. Careful attention was paid to the deployment of the variation in the way points are picked. Previous picking methods were evaluated and a notational system was developed to depict those conditions. The estimated crease lines (indicated blue) in the drawing were compared and analyzed against the crease of the actual cast. The revised crease lines (indicated in orange), begins to form a “logic” of crease lines form the types of point picking and its relations to one another. This is particularly an important tool in projecting the surface characteristics of complex smocked surfaces yet to be fabricated.

CONCLUSIONS

The following general conclusions were extracted from the results of the short focused experiments.

"Smocking" is a surface articulation naturally drawn out of the fundamental properties of fabric and liquid captured in a hard surface, a manifestation of an equilibrium reached between the surface tension of the fabric and the omni-directional hydrostatic pressure of the concrete in a liquid state. It is a dynamic self-organizing process that the result cannot simply be depicted pictorially. The notational drawing system developed and introduced in the experiment precisely documents the fabrication process and implies formal characteristic of the result. It is just enough information to contemplate and to project the design alteration of fabric formwork.

Being able to control such surface articulation has a potential for application beyond the qualitative attractiveness of the surface geometry.

Concrete is known for its high thermal mass (inertia), absorbing and storing heat when the surrounding temperature climbs higher and releasing heat when the surrounding temperature drops lower. This generally translates to a temperature stabilizing effect ideal for the dry desert climate, leading to the energy savings for heating and cooling of the building. Optimizing the surface geometry for heat gain or loss can further enhance this property. Jason Vollen et al. have conducted a similar exploration in a ceramic masonry wall system.[14] However, it is not exploited as a sustainable solution for a concrete building system.

The smocking technique can potentially be applied to manufacture visually unique concrete panels with complex three-dimensional surfaces, calibrated to control the solar heat gain and loss over time.

Another potential interest is to look into the structural performance of the smocked surfaces. Funicular geometry of the fabric-formed concrete already has a significant structural advantage. Crease lines in the smocked surfaces are naturally manifesting force lines. When cast, crease lines turns into ribs on the surface. An approach to begin analyzing the performance of such complex surfaces is to engage the latest digital simulation technologies. The next logical development for the author is to gain proficiency in reverse engineering an accurate digital model of the smocked surfaces. This is an attempt to engage digital technology in parallel to the fundamental material properties, not an attempt to subvert the resistance and limitations. It is the key to unlocking the natural potential of the low-tech material in the brave new high-tech world.

ENDNOTES

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