Sphere Mapping: a method for responsive surface rationalization

Chris Beorkrem, Mitchell McGregor, Igor Polyakov, and Nicole Desimini

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The method proposed in this project addresses the parametric manipulation of a given pattern to respond directly to a parametric surface. The research attempts to propose a method for attaching fixed sized objects to a free flowing surface or "blanket." The model can be used to interrogate a series of shapes and forms with the same componentry. Continuing the research of Kevin Rotheroe, Yale University and founder of FreeForm Design. Rotheroe and his students developed a series of studies in material and surface properties. By utilizing a proven pattern, the proposed method sets parameters derived from the formal properties of the original pattern and produces a new pattern that is responsive to the curvature of a complex surface. The workflow developed in this research consists of a complex blending of tools in *Rhino Grasshopper* and Gehry Technologies *Digital Project.* The intent is to achieve the aesthetics and structure offered by Rotheroe's original research and to add a responsive precision that provides an accurate adaptation of the pattern based on curvature of a specific computationally defined surface.

1. INTRODUCTION

The exploration of adaptable surfaces in the field of architectural research is pertinent to elements such as façades, building skins, and interior walls and surfaces. It allows a single pattern to be applied to any given surface within a building while responding to the constraints of those surfaces. Parametric software has made complex structural systems tangible and doubly curved surfaces feasible. Rotheroe (2001a) investigated cut patterns, which were explored using plastic bent forms in steel. The surfaces analyzed here, address material and production constraints, pattern study, and modeling processes. The studies focus on maintaining the purity of the patterns and exposing their limitations on a flexible surface shape. Each unique piece of geometry was tested first as a physical set of components, which could then be pushed into a variety of shapes and forms, testing the limitations of the geometric pattern, through physical models.

The intent of the following research was to test a parametric model that rationalizes a tessellation patterns as a response to an undefined surface. The physical tests of patterns have primarily been the simplest method for articulating the range of possible forms for each pattern. The intent of this research was to ensure the proposed method would adapt to the scale and shape of the pattern on a given surface. In this method, Rotheroe's (2001b)

► Figure 1. Drawing pattern and respective diagram of plastic bending formation.
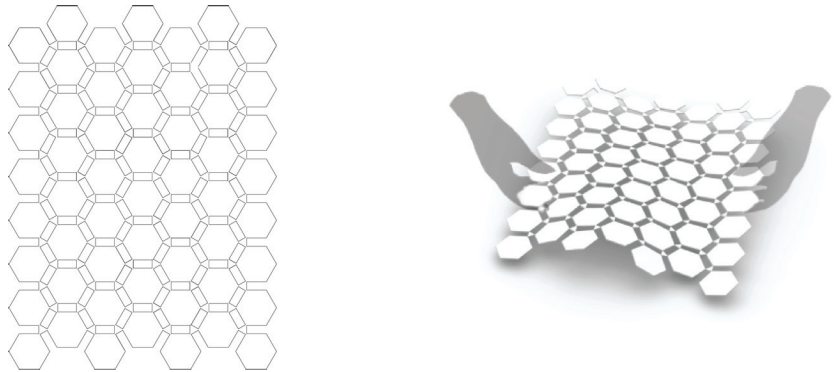
► Figure 2. Physical (left) and parametric (right) reproduction of original patterns flowing on a surface.
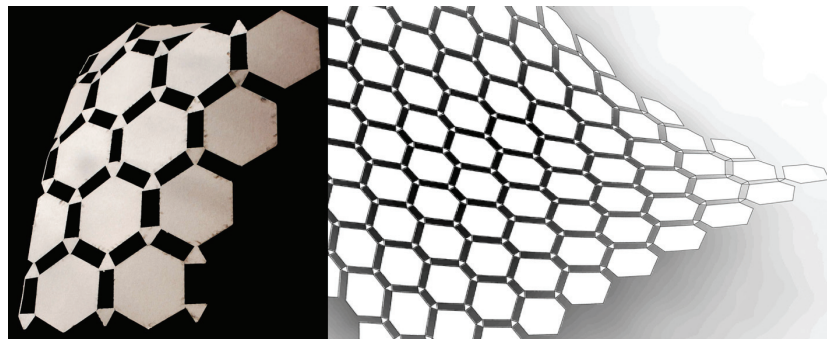
workflow of pattern before surface is reversed, resulting in a pattern that responds directly to a complex surface. Eventually subtractive CNC plasma-cutting was be used to produce the resulting surface, which was overlaid on a plywood eggcrate to confirm its geometric capabilities.

2. PARAMETRIC MODELING WORK FLOW

2.1. Sphere Mapping

This process mapped out in the following pages was created entirely through geometric relationships in Gehry Technologies, *Digital Project* and *Rhino Grasshopper*. In *Digital Project*, the process of Sphere-Mapping can be applied to a given surface. This technique creates a triangulation on the surface by creating spheres that intersect with the surface. To start the process, the pattern and triangles that form the hexagons are laid out two-dimensionally. The triangles provide the radius of the spheres with their dimensions in addition to providing the dimensions of the hexagonal shapes (see figure 3).
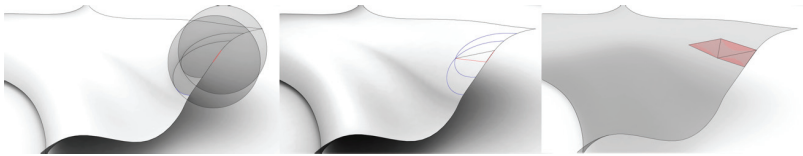
◄ Figure 3. Sphere-mapping process. Sphere intersecting with surface (left). Resulting lines projected on surface (center). Resulting mapped triangles (right).

In order to map the triangles, two isocurves are created on the surface; one in the 'u' direction and one in the 'v' direction. The intersection of the two isocurves is used as the center point for the first sphere of the sequence. The sphere and the surface intersect to create a curve on the surface (whose points are all equidistant from the center of the sphere). To construct the next sphere, the previous steps are repeated with the second radius given by the corresponding triangle of the two-dimensional layout. The point of intersection of the two curves is the first point of the triangle. In this particular pattern, however, there are two sizes of triangles. One set comprises the hexagons while the second set is used for spacing between each hexagon. A triangulated structure is the result of the sequence. The sequence must free itself from the surface, operating in the center of the form, free to "flow" on the surface as the triangulation necessitates. It should be noted that this process can be constructed in *Digital Project* upon a parametric surface, whereby the triangulation can be recalculated should the original surface be changed. Though the intersections of the panel systems must remain on the surface or the panel will fail as the spheres no longer intersect with the surface.

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3. SURFACE DIVISION

The final workflow involves processes that require the geometric flexibility of tools in *Rhino Grasshopper* and the geometric precision and rapid replication provided by *Digital Project*. In this method, *Rhino Grasshopper* was to develop a parametric process for linking triangulation sizes or pattern sizes to the twist and radius of the curvature. The intent is to generate a surface to which a pattern can be flexibly applied. In order to achieve a regular partition of the given surface, the "Divide" and "Subsurface" tools are used. The result is a surface of triangles of approximately the same size. Next, the surface was further divided using a mesh, the partitioned surface was divided into more responsive and articulated triangles. The division produced by mesh tools is affected directly by the curvature of the surface. However, the outcome is not functional until a "Delaunay" tool was applied to subdivide the surface and make the triangle sizes responsive to the radius of the curvature.

"Delaunay meshes" produce appropriately responsive subdivisions by avoiding the typically thin triangles of conventional meshes. Delaunay meshes by their definition create triangles which have vertices with the largest angle possible at each vertices. This creates an idealised form as it minimises the difference between each adjacent triangle.

First, precise changes on the surface were defined that respond to the twist of surface in certain places. Triangles become smaller as the radius of the surface decreases. Second, the angle tolerances are controlled to avoid extreme changes in the surface. When a surface curves beyond a certain point, the Delaunay mesh tool divides the area undergoing the relatively extreme radius into smaller triangles. This allows the surface to bend. The lines of the curved surface were translated onto flat surfaces created by "unrolling" the original curved surface. The outcomes are precise, however, *Rhinoceros* restricts the use of the "unroll" command in cases of doubly curved surfaces. Therefore, the responsive surface at this moment is either singly curved or requires stitches between breaks to reconnect splits or slots between zones of the surface.

4. APPLICATION OF PATTERN TO SURFACE

The process shifts to *Digital Project* as the software's has the ability to apply a pattern iteration to multiple surfaces, producing derivations of the original pattern that respond directly to new versions of the surface. Inside of Digital Project the user is capable of creating adaptive geometric linkages between Rotheroe's hexagonal pattern and the Delaunay triangulation. The "power copy" process allows a shape to be copied to a separate area of the surface while keeping the original properties of that shape intact. In this instance each hexagon and its relationships is maintained while the entire shape shifts to adapt to the size of each mesh triangle. Using the two-

dimensional file imported from *Grasshopper,* the points of the existing triangles are used to locate the points of the hexagons. Within this particular pattern, there are two different types of hexagons and three different types of triangle joints. The set of hexagons consist of alternating rows of dominant hexagons and recessive hexagons. The three triangle joints are necessary in order to address the different orientations of the joints. In order to maintain consistency throughout the pattern, a separate "copy" is necessary for each type of shape (see figure 4).
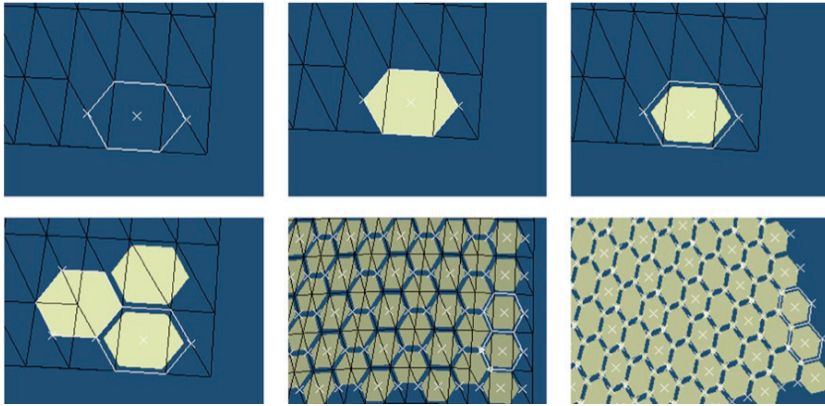
4.1. Instantiation Process

Beginning with the main hexagon, six points are located on the triangles of the original mesh to construct a surface. In order to compensate for the spacing between each hexagon in the original pattern, a copy of the hexagon is scaled down in size. The original hexagon is then hidden. The workflow of *Digital Project* does not allow objects to be erased after a power copy has been made. The copied object is directly linked to the original, and will lose any data if the first shape is deleted. Therefore, in order to simplify what is viewed, the original shape is hidden. Each copy of the hexagon is instantiated throughout the original mesh. The resulting hexagonal surface contains the same properties as the original but responds directly to the points selected. In this phase, the variation in shape and size is evident. To create the proper pattern, each row consists of several of one of the two hexagonal power copies. Each original power copy must be made prior to the replication of shapes.

## 4.2. Preparation of Cut File

The model is now exported as a drawing and imported back into *Rhinoceros.* We elected to test the subtractive construction method for both the CNC Laser Cutter and CNC Plasma Cutter machines. In order to fit the cut file to a given sheet size, in this case 4'-0" by 8'-0", a box of the

given dimension is drawn around the imported drawing. Any hexagons that do not fit onto the sheet were trimmed from the drawing. As the original pattern consumed roughly this same area, the shifted version of the drawing would inevitably be slightly larger in some dimensions. The proportions of each type of cut were matched to the thickness of the material. For chipboard, .022", and for 20 gauge steel- .0359. The resulting pattern consists of hexagonal shapes, separated by four-sided gaps, and triangles at the connectors. The entire surface consists of planar shapes that bend only at the points where hexagons meet a triangle: there are no curved shapes. The resulting file is the hexagonal pattern that is ready to be cut into the full sheet or scaled down to do mock-ups.

4.3. Radius and curvature analysis

The analysis of the curvature radius is important in order to understand whether or not the pattern can adhere to the limitations of the material, in this case, 20 gauge steel. The responsive properties include tessellation only on each "twist" of the surface. This definition can be changed where the extreme radius of 16" is present (see figure 5). The bent surface at the edge will tessellate (see figure 6). This shift in the size of the hexagons is a direct

► Figure 5. Radius of the curve with changing tessellations.
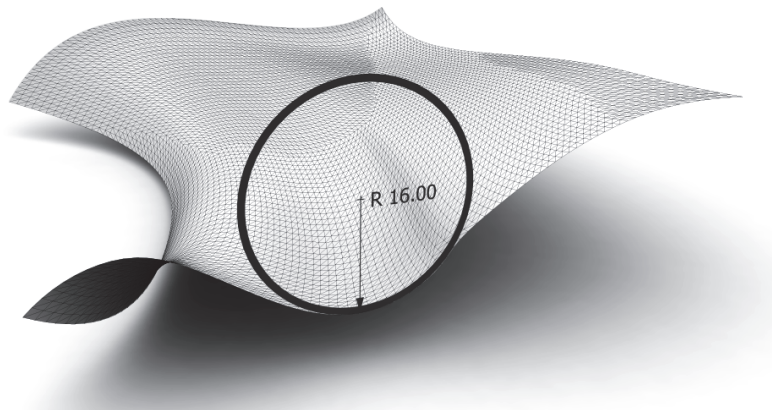
► Figure 6. Tessellations (triangles) converted into hexagons have different sizes but are related and proportional to original surface geometry.
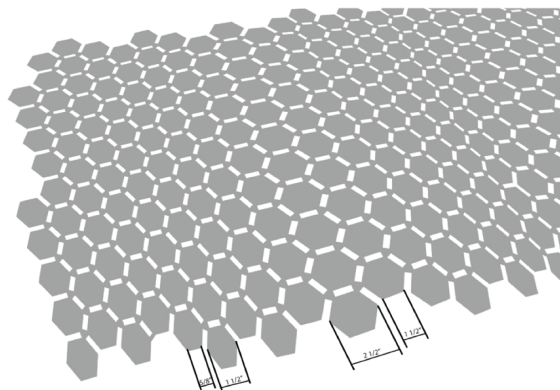
response to the twist of the surface. This explains why that particular portion of the tessellation changes (see figure 5). Because the hexagons were derived from triangles and do not match the original tessellation exactly, sizes are different but are proportionate to the original curvature of the surface.

5. MOCK-UP PROCESS

Once the cut file is ready, a series of mock up models were generated (see figure 7) to test the outcomes to scale. The production of scaled and full size models, using pliable materials, such as chipboard, defined inaccuracies or failures within the pattern. It also afforded us a test to determine whether the *Grasshopper* pattern is physically capable of bending to the surface. After the cut file was modified according to the chipboard mock-up, we cut a portion of the file from a 20 gauge steel sheet, 2'-0" by 2'-0", on a CNC plasma cutter (see figures 8 and 9). The egg crate (intersecting contours of surface) made in stage three is created to verify the accuracy of the chipboard model and to test the accuracy of the process.
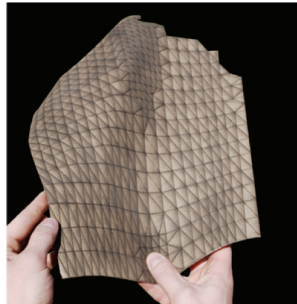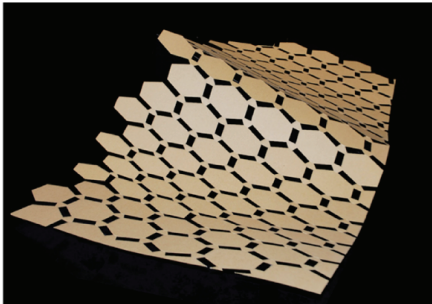
◀ Figure 7. Laser cut chipboard mock up of final pattern and triangle mesh.
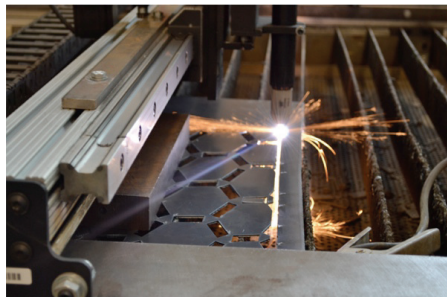
◀ Figure 8. CNC plasma cutting in progress.
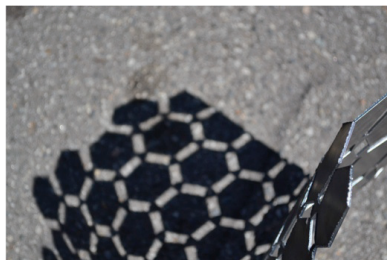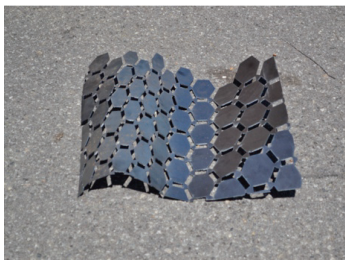

◀ Figure 9. Final test cut.

5.1. Egg Crate

In order to accurately test the final product, the surface was applied to an egg crate structure. The egg crate was used as a tool to produce an approximation of the precise bend of the surface. Using a CNC router, ¾" plywood was cut and assembled (see figure 10).

5.2. Final Surface

The next phase of the process entailed the use of a CNC plasma cutter to cut 20 gauge steel test sheets. Explorations in this phase include the testing of cut line variations, and the analysis of the sheet's ability to achieve the proposed curvature. The eggcrate was intended to function as a guide for the metal. The piece was laid over the structure and going from one end to the other is slowly bent to the egg crate. The goal is to form the metal to the egg crate as well as it can until the joints start to stretch and compromise their geometry. This shows us where the constraints of the material and the pattern/method meet.

▼ Figure 10. Final surface formed over egg crate.
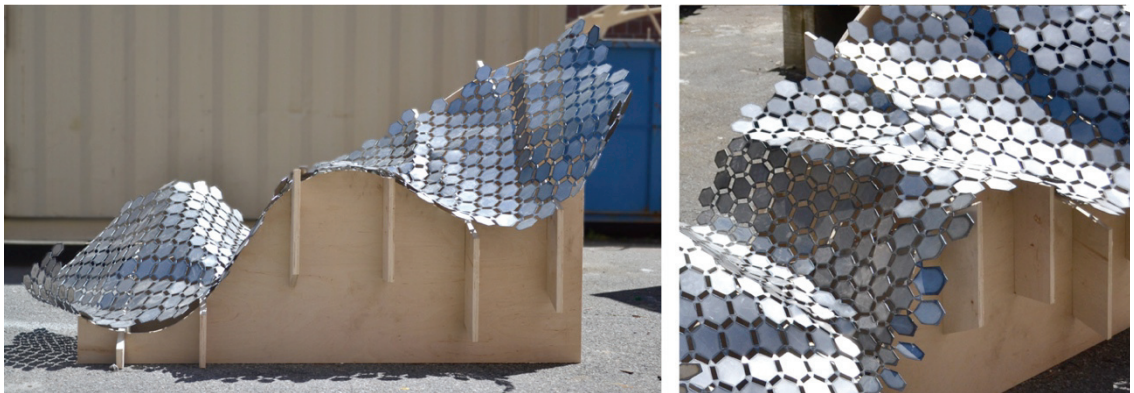
6. CONCLUSION

6.1. Overview

The surface produced proved the proposed method to be successful in several ways. The expectations of creating sub-divisions that correspond directly to the curvature of a given surface were met (see figure 11). The pattern components varied in size in the desired areas, allowing the metal to take the proper form. The gradual dimension change of the original triangles reciprocated in the transition of hexagons. Overall, the surface adhered to the same aesthetic quality of the original Rotheroe pattern while maintaining structural integrity. The elegance and precision present in the original pattern were actually enhanced through further articulation. The
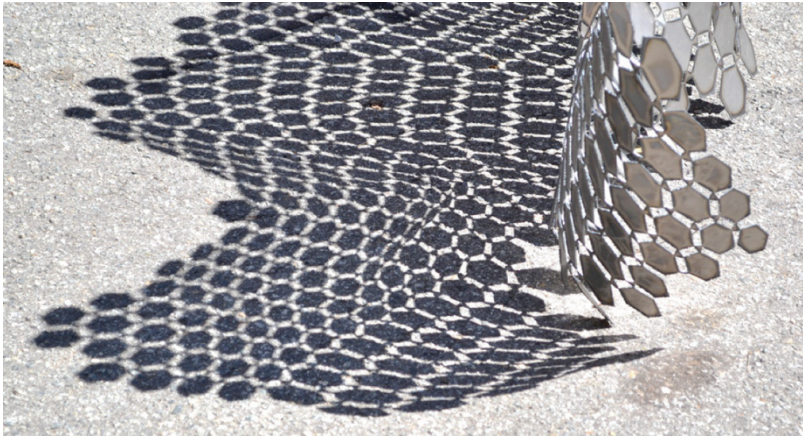
◄ Figure 11. Shadows displaying change in size of hexagonal patterns.

connections proved relatively strong and provided ample flexibility to support the bending of the metal. The triangles serviced the bending requirements, and alleviated any harsh or drastic bending by the introduction of smaller hexagons in areas of extreme curvature.

6.2. Future Work

The product of this process is a study to understand the strengths and weaknesses of a responsive pattern system. However, understanding the constraints of the system, the applications became more evident. The ultimate intent was to create a pattern that can respond in size to the complexity of a surface. The current system responds rather well, however, it would benefit from further iterative studies in order to understand the optimum connection for the pattern and material. The process is applicable to the study of other material constraints, which could be defined as responsive to materiality, surface and form.

REFERENCES

1. Gonchar, Joann. "Transformative Tools Start to Take Hold: A Critical Mass of Building Information Modeling Projects Demonstrates the Technology's Benefits and its Potential for Redefining Practice." *Architectural Record*. Apr. 2007: 155-162. Hinte, Ed Van., Cesare Peeren and Jan Jongert., eds. Superuse: Constructing New Architecture by Shortcutting Material Flows. Rotterdam, NE: 010 Publishers, 2007.

2. Kolarevic, Branko. *Architecture in the Digital Age: Design and Manufacturing*. Oxford: Routledge, 2005.

3. Kolarevic, Branko. And Kevin Klinger. *Manufacturing Material Effects: Rethinking Design and Making Architecture*. New York: Routledge, 2008.

4. Rotheroe, K.: (2001), Manufacturing Freeform Architecture, *in* Bechthold, M., Griggs, K., Schodek, D. and Steinberg, M. (eds.), *International Symposium on New Technologies in Architecture: Computer-Aided Design and Manufacturing Techniques*, Harvard Graduate School of Design, Cambridge, 43–47.

5. Rotheroe, K.: 2001, Design and Build, *Architects' Journal,* **10**, 46–47.

6. Rotheroe, K.: 2001b, Supermodels Get Down to Work, *Architects' Journal,* **11**, 44–45.

7. Reiser, Jesse. *Atlas of Novel Tectonics.* New York: Princeton Architectural Press, 2006. Schodek, Daniel. Digital Design and Manufacturing: CAD/CAM Applications In Architecture and Design. Hoboken, NJ: John Wiley & Sons, Inc. 2005.?Staib, Gerald. Components and Systems: Modular Design, Structure, New Technologies.

8. Sakamoto, Tomoko. And Albert Ferre., eds. *Parametric / Algorithmic Architecture From Control to Design.* Barcelona: Actar, 2008.

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