SPHERE MAPPING

A method for a responsive surface rationalisation

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Abstract. The method proposed in this project addresses the parametric manipulation of a given pattern to respond directly to a pre-defined surface. Continuing the research of Kevin Rotheroe, Yale University and founder of FreeForm Design. Rotheroe has developed a series of studies in material and surface properties. By utilising 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 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.

Keywords. Geometric systems; parametrics; material constraints.

1. Introduction

The exploration of adaptable surfaces in the field of architectural research is pertinent to elements such as façades, building skins, and interior façade 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 patterns and the various methods of construction (see Figure 1), which release materials into plastic bent forms. The surfaces produced address material and production constraints, pattern
study, and modelling processes. The studies focus on the purity of the patterns and their limits. The intent of following research is to extend the research is to test a parametric model that rationalises a tessellation patterns as a response to a predefined surface. The proposed method will adapt a pattern to a given surface. In this method, Rotheroe’s (2001b) workflow of pattern before surface is reversed, resulting in a pattern that responds directly to a complex surface. Furthermore, the production strategy of subtractive CNC plasma-cutting will be utilised to produce the resulting surface.

![Figure 1. Physical (left) and parametric (right) reproduction of original pattern.](image1)

2. Parametric modelling work flow

2.1. SPHERE MAPPING

This version of the process was mapped entirely through geometric relationships in Gehry Technologies, Digital Project and Grasshopper. In Digital Project, the process of Sphere-Mapping is applied to a given surface. This technique creates triangles 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 the hexagonal shapes (see Figure 2).

![Figure 2. Sphere-mapping process in Digital Project. Sphere intersecting with surface (left). Resulting lines projected on surface (centre). Resulting fixed size triangles (right).](image2)
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 centre 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 centre 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 the hexagons. A triangulated structure is the result of the sequence. The sequence must free itself from the surface, operating in the centre of the form, free to “flow” on the surface as the triangulation necessitates.

3. Surface division

The final workflow involves processes that require the geometric flexibility of tools in Grasshopper and the geometric precision and rapid replication provided by Digital Project. In this method, 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 implemented. The result is a surface of triangles of approximately the same size. Next, the “Mesh” command is applied to further divide the partitioned surface 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 the “Delaunay” tool is 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 with the maximum sized angle of the 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 increases. 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. Grasshopper is used to transition into Digital Project. The “Mapping” tool makes it possible
to transform all the lines of the curved surface onto a flat surface 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.

Application of Pattern to Surface

The decision to move the process to Digital Project is validated by the software’s ability to apply a pattern iteration to multiple surfaces, producing derivations of the original pattern that respond directly to the new surface. After much exploration, the “power copy” process in Digital Project proved to be the most efficient tool for creating the 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. 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 “power copy” is necessary for each type of shape (see Figure 3).

![Figure 3. Power copy process.](image)

3.1. POWER COPY 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. To replicate the “power copy”, the first hexagon is
selected followed by the “Instantiate Form Selection” tool. The resultant new
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.

3.2. PREPARATION OF CUT FILE

The model is now exported as an “.igs” drawing and imported into Rhinoc-
eros. 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 are “trimmed” from the drawing. 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.

3.3. 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 “twist”
of the surface. Definition can be changed where the extreme radius of 16”
present (see Figure 4). The bent surface at the edge will tessellate (see Figure
5). The change in size of the hexagons is the direct response to the twist of the
surface. This explains why that particular portion of the tessellation changes
(see Figure 4). 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.
4. Mock-up process

Once the cut file is ready, mock up models were generated (see Figure 6). The production of scaled and full size models using 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 have been 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 7 and 8). The egg crate (intersecting contours of surface) made in stage three is cut and assembled to verify the accuracy of the chipboard model and to achieve the accurate mapping of the surface.
4.1. 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 accurate and precise bend of the surface. Using a CNC router, ¾” plywood was cut using a two dimensional drawing arranged onto 4'-0” by 8'-0 boards (see Figure 9).

4.2. 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, material property studies the analysis of sheet’s ability achieve the proper curvature. The egg crate functions as a guide for the metal. The cut hexagonal sheet will not fit exactly to the egg crate, this is part of the explora-
tion of material/method constraints. The piece is 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 9. Final surface bent over egg crate.](image)

5. Conclusion

5.1. OVERVIEW

![Figure 10. Shadows displaying change in size of hexagonal patterns.](image)

The surface produced proved the proposed method to be successful in several ways. The expectation of creating sub-divisions that correspond directly to the curvature of a given surface were met (see Figure 10). 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 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.

5.2. 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