

Aesthetic of Periodic, Non-Periodic, Stochastic, and TPMS in Digital Sculpture

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Abstract

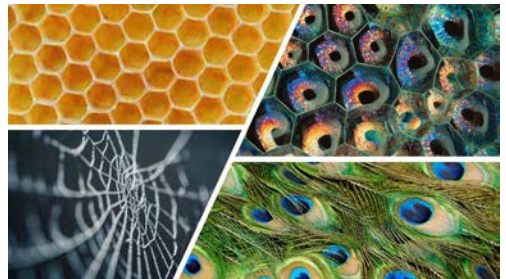
Introduction:

Different structures can fill a volume, and in nature, we can find examples in bones, honeycombs of beehives, fungi mushrooms, bubbles (as Voronoi structure), bird feathers, and spiderwebs.

All these examples are nature's way of filling a volume and providing lightweight structures but also present a natural beauty that we respond to.

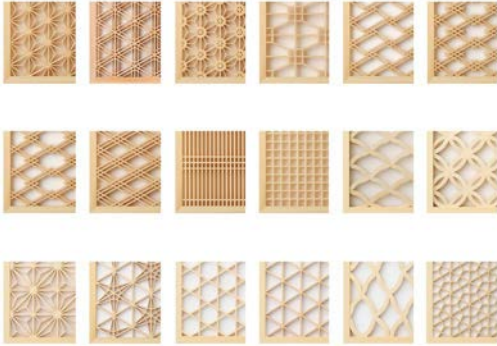
Our aesthetic response to lattice structures is influenced by a combination of symmetry, complexity, transparency, cultural context and experiences, and the interplay of negative and positive space

defined by the structure itself and the intrinsic light and shadow. All these elements combine to create a visual experience that many find inherently beautiful and captivating.



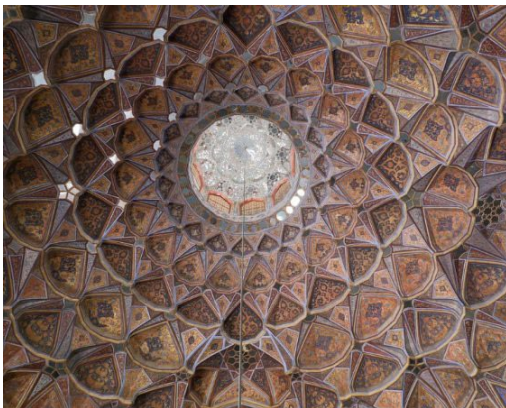
Since a few years ago, such structures have been used primarily in 2D design to translate complex three-dimensional shapes.

For instance, we can find some examples of this kind of translation in the Japanese art Kumiko, a traditional wood-making technique in which the wood pieces are assembled without using any nails. Two-dimensional patterns are translated into three-dimensional ones mostly to make screens.



In Islamic art, other designs are built on squares and circles, typically repeated, overlapped, and interlaced to form intricate and complex patterns. A recurring motif is the 8-pointed star, often seen in Islamic tilework; it is made of two squares, one rotated 45 degrees to the other.

The two dimensional patterns were also translated into impressive architectural structures.



We are just beginning to explore more complex patterns that AM (additive manufacturing technologies) made possible to fabricate in 3D. Most recent studies are related to increasing these structures' versatility because of the significant benefits like high strength-to-weight ratio.

Objective/Hypothesis:

In this research, a novel approach to studying cellular lattice structure focuses on the aesthetic response of structures that fill a mesh, a CAD model, or surfaces. Lattices can be periodic, non-periodic, or stochastic, modeled through beams, plates, or (TPMS) Triply Periodic Minimal Surfaces.

My research aims to investigate the correlation between lattice structures that mimic natural patterns, such as honeycombs, leaf veins, or crystal formations, as natural forms with an inherent beauty that resonates with many people.

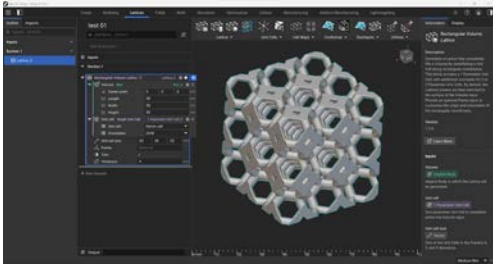
By using the latest software (nTopology, NetFabb, Fusion 360, etc.) and specific processes to prepare a variety of sculptures, I explore the aesthetic response based on symmetry and order, transparency and light play, complexity and intricacy, natural and cultural connection, functional elegance, cultural significance, dynamic perception, scale.

Methods:

The research uses nTopology design software to prepare small samples to test the aesthetic response with a pool of people.

As a first series of lattice structures, I set up a basic cube 50x50x50 mm with a unit cell of 25x25x25 mm. The minimum thickness of the elements was defined as 3 mm. These dimensions were selected to create a series of easily printable models that can fit a hand and be analyzed by the pool by visual inspection and tactile experience. I modeled the dimensions for the Printing with an SLA 3D Printer (Formlab 3) that provides a smooth finish and doesn't need support

with smaller parts with printing angles less or equal to 45. Prints are made in white resin to avoid any color connotation and to improve the understanding of negative and positive space based on the white materials and their shadows.

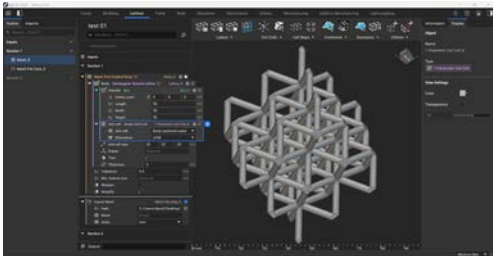


I divided the models based on four subdivisions (Periodic, Non-Periodic, Stochastic, and TPMS), and I started with a single parameter graphic unit cell.

Some periodic lattices are often considered aesthetically attractive due to their symmetrical and visually appealing patterns, so I grouped some of them and selected five as the best representatives:

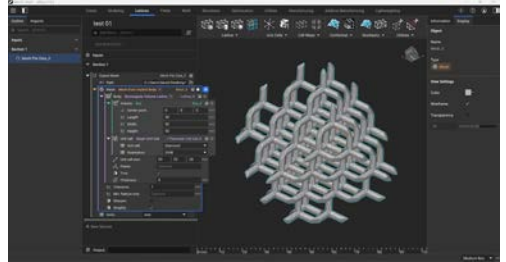
The body-centered cubic (BCC) cell is a typical crystal lattice structure in solid-state physics and materials science. It is characterized by its simple cubic unit cell.

From an aesthetic standpoint, the body-centered cubic lattice may be appreciated for its clean, regular, and symmetrical pattern.

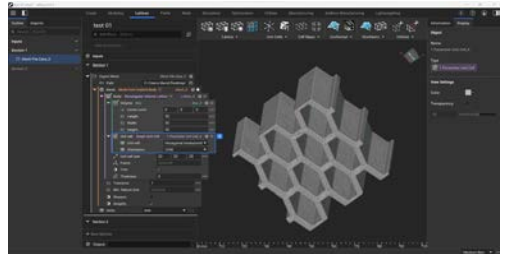


The diamond lattice is a face-centered cubic lattice structure, often associated

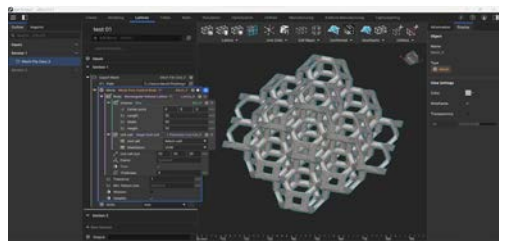
with the crystalline form of diamond. It has a symmetrical and geometrically pleasing arrangement of parts.



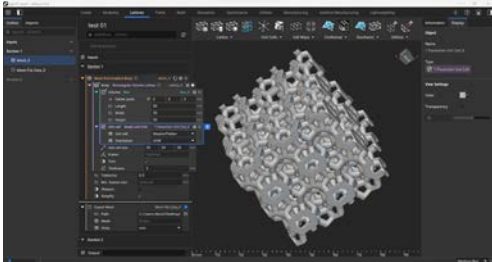
The honeycomb lattice is composed of hexagonally arranged cells, similar to the structure of a honeycomb. It can be found in materials like graphene, and its regular hexagonal pattern is often considered visually pleasing for its natural reference.



Kelvin unit (Tetrakaidecahedral unit-cell representation) is based on filling space with a structure that minimizes surface area. It consists of a unit cell shaped like a tetrakaidecahedron, which is a polyhedron with 14 faces (8 hexagons and 6 squares). Some may find its intricate, interlocking patterns visually captivating.



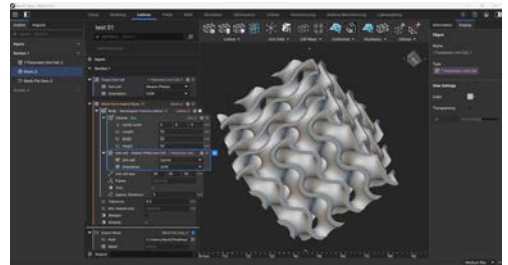
Weaire-Phelan is a complex foam-like arrangement of cells with the minimum known surface area for a partition of space into cells of equal volume. The structure consists of two types of cells: "Weaire cells" and "Phelan cells." Weaire cells are irregular dodecahedra, while Phelan cells are irregular polyhedra with 14 faces, including 12 pentagons and two hexagons. These cells interlock to minimize the total surface area, making it an optimal way to partition space into cells of equal volume. From an aesthetic standpoint, the Weaire-Phelan structure can be visually intriguing due to its intricate, irregular shapes and how they fit together.



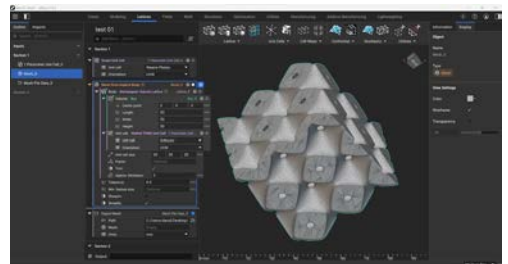
Triply periodic minimal surfaces (TPMS) divide three-dimensional space into cells of equal volume with minimal surface area. I modeled and printed a series with the exact dimensions and thickness for a starting base.

The Gyroid lattice is a fascinating and visually captivating mathematical structure. It is a triply periodic minimal surface, meaning it fills space with the least amount of surface area possible. This lattice was first discovered by physicist Alan Schoen in 1970. In addition to having parallel surface symmetry lines, the gyroid is notable for having no right-angle portions on its surface.

Aesthetically, many people find the Gyroid lattice to be highly interesting and visually appealing. Its continuous, interconnected network of twisting surfaces creates a mesmerizing and captivating visual experience. The lattice's intricate and repeating patterns can evoke a sense of wonder and curiosity.

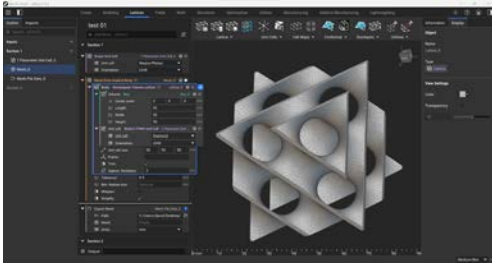


The Schwarz lattice refers to the "Schwarz P surface," a triply periodic minimal surface. This surface was first described by Hermann Schwarz in 1890. Aesthetically, its intricate, interconnected pattern can be mesmerizing to look at, and in the past, it has also found applications in architecture and materials science.



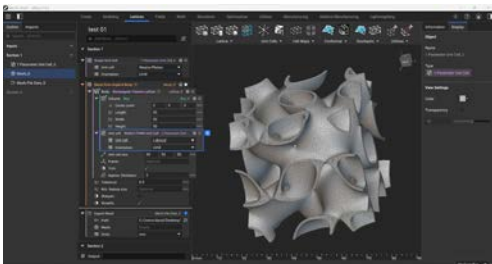
The diamond TPMS is characterized by a repeating pattern of diamond-shaped cells with intersecting edges and vertices. It is symmetrically and geometrically pleasingly.

To make it more similar in structure to all other ones, I had to change the size of the cell to 50x50x50 mm.

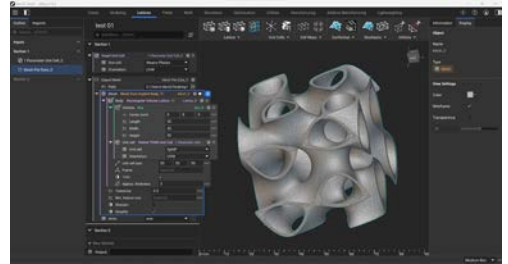


The Lidinoid is another example of TPMS. In 1990 Sven Lidin and Stefan Larsson found in the associate family of a particular member of the Schwarz H-surfaces this new embedded triply periodic minimal surface, similar in appearance to Alan Schoen's Gyroid.

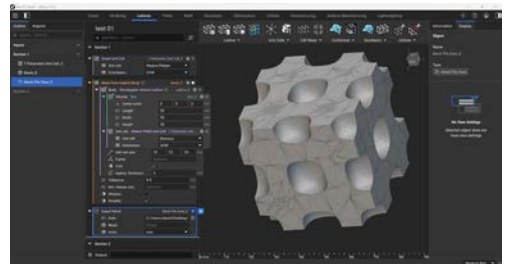
The Lidinoid has a distinctive undulating, curved structure with interconnected channels and chambers. It is characterized by its repeating, labyrinthine pattern that fills space with minimal surface area. Aesthetically, the Lidinoid is appreciated for its complex and visually captivating form. Its repeating pattern and interwoven curves create a visually exciting and mesmerizing structure.



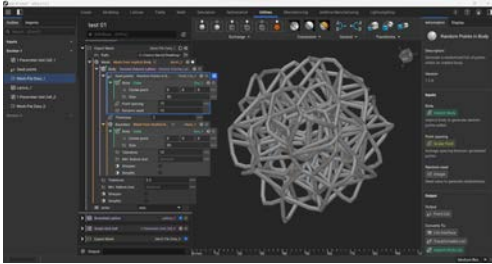
The SplitP is another interesting TPMS similar to the Linoid with a similar repeating, labyrinthine pattern.



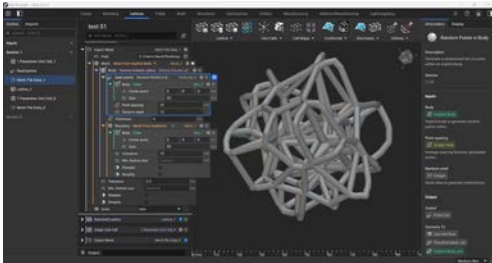
The Neovius surface is a triply periodic minimal surface originally discovered by Finnish mathematician Edvard Rudolf Neovius. Neovius' minimal surface in a unit cell has genus 9, dividing space into two infinite non-equivalent labyrinths. It presents a distinctive interconnected pattern of curved surfaces and is characterized by its repeating, labyrinthine structure with symmetrical features.



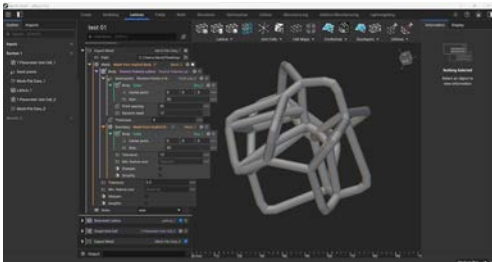
For the stochastic lattices, it was a little more challenging to establish basic parameters because to keep the structure similar in size and proportions to the previous ones, I had to change many parameters (random seeds creation, number and distance of points, etc...) I ended up in creating a series of structure, by using the same cube, but increasing the point spacing and at the same time increasing the thickness until the cube wasn't perceived anymore.



Point spacing 10, thickness 2



Point spacing 20, thickness 3



Point spacing 30, thickness 4

After modeling these basic samples, I 3D printed them with an SLA printer.

The analysis involved giving the 3D Printed samples to art students and gathering their opinions and reactions to the models. The evaluations were done by providing an aesthetic value from 1 (less appealing) to 5 (very appealing).



Another consideration is that the 3D printed models were evaluated for their aesthetic and tactile experience. People had an enhanced perception by holding the models in their hands.

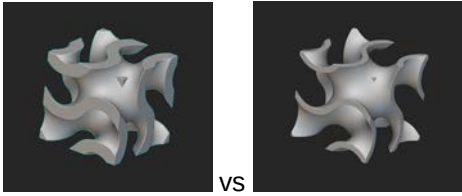
It seemed that models with softer curves were more appealing to a more significant number of people for the intrinsic tactile quality.



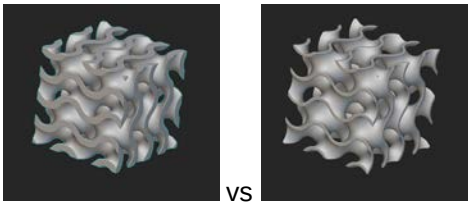
Results:

The TPMS group of lattices received the highest evaluations with the giroyd as first choice.

Additional evaluations were successively made on the proportions of the wall thickness respect the module and the proportions between the module and the volume to be filled.



Unit Cell Size 50x50x50 mm with thickness 10 mm vs thickness 5 mm.



Same unit cells 50x50x50 mm with thickness 10 mm vs thickness 5 mm to fill a cubical volume of 100x100 mm.

The pool of people evaluated more positively the gyroid with thinner walls.

Conclusions:

Sculptures that use the gyroid as a lattice structure to fill part or entirely the volume of the form received a higher aesthetic evaluation, especially with thinner walls. To create a modeling process for the modeling with lattice structures, we need first to establish the fabrication technology that will be used. A 3D Printed sculpture in SLA can probably be printed with thinner walls than one printed with binding jetting or FDM. A minimum thickness between 2 and 3 mm is necessary for good strength. The minimum thickness of a CNC carved sculpture (wood or stone) must be much higher. The size of the lattice structure cells must be established by considering the manufacturing technology. This limitation will also impact the main proportions of the lattice structure that fills the space.

"Noble Woman", one of the first sculptures I modeled with lattice structures as the fill of the internal volume, had a minimum thickness of around 3 mm. The internal lattice structure worked well with the external volume, creating an interesting dialogue between the parts.

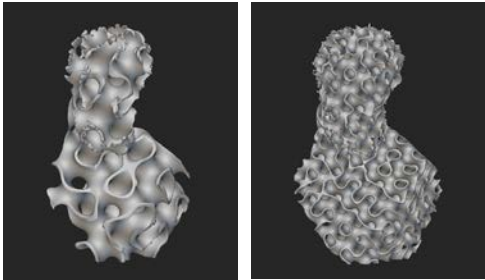


Model Examples:

By exploring a series of sculptures made with the use of gyroid as aesthetical component I can provide some initial considerations:



Dimensions need to be established already at the beginning of the modeling.



Key words: Generative design, additive manufacturing, 3D Printing, computational design.

Proportions of the unit cell size and thickness need to be carefully evaluated based on the details of the model and its elements. In my research, it is important to find correlations between the external volume and the lattice structure by opening the volume in the "right" areas. I can carefully balance the relationship between "internal" and "external" shapes with cuts and by removing entire parts that become no longer essential. When well positioned, the showing of the lattice structure enhances the missing details of the sculpture.

