Nature Inspired Shapes and Design of Engineering Applications

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Abstract: Engineering design has long been dominated by orthogonal Cartesian principles. Nature inspired equation based mathematical surfaces are under renewed interest due to their innovative design potential and practical viability by 3D printing. In this paper, the parametric surface modelling feature of COMSOL is leveraged for developing engineering structures from equation based mathematical surfaces. The ability of parametric model for creating and visualizing complex shapes is detailed. Mathematical surfaces such as, Fresnel's Wave, Klein, and Gyroid surface and applications are elaborated with surface to engineering applications link. As the 3D printing industry is growing from small scale to mainstream product manufacturing, equation based surface models will enable 3D printable innovative engineering applications.

Keywords: Analytical Surfaces, Engineering Surfaces, mathematical surfaces, Nature inspired shapes, Engineering, Architectural shapes.

1. Introduction

Nature evolved over millions of years to produce remarkable surfaces and shapes. Nature inspired, equation based mathematical surfaces were developed over many centuries. Sample inspiring and complex mathematical Surfaces are shown in figure 1. These intriguing shapes and surfaces based applications are confined within the mathematical and simulation domain for centuries, due to limitation in conventional manufacturing methods, cost effectiveness and practical feasibility. Recent developments in 3D printing and CAE, empowers to make these complex shapes a practical reality and hence the renewed interest. In this paper various nature inspired equation based mathematical surface are developed in COMSOL, leveraging parametric surface feature. A list of surface from Archimedean spiral to Wallis's Conical Edge was developed. These surfaces were used to build engineering products. Select surfaces, governing mathematical equation, CAD model and Engineering product details are detailed.

2. Equation based Surface model and applications

The CAD model building capabilities of COMSOL Multiphysics Simulation software is leveraged for equation based surface model and product development. We have developed parametric COMSOL models of more than 25 surfaces. However, the details of Fresnel's Wave, Klein, and Gyroid surface and applications will be detailed.

2.1 Fresnel's Wave Surface

Fresnel's wave surface is a quartic surface describing the propagation of light in an optically biaxial crystal. Wave surfaces are special cases of tetrahedroids. The wave surface is created using parametric surface feature of COMSOL design module. This wave surface is then converted into 3D print models with patterns of nature inspired structures as shown in figure 2 for multitude of fresnel wave organic structure based applications.

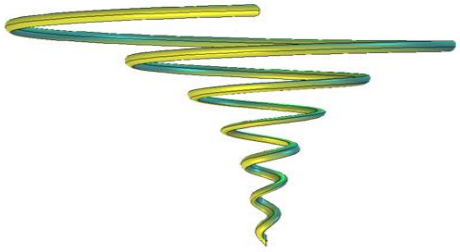

Fig1a Nature inspired Surfaces: Archimedean spiral

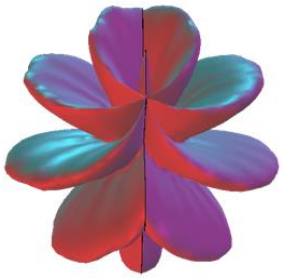

Fig1b Nature inspired Surfaces: Parametric sphere

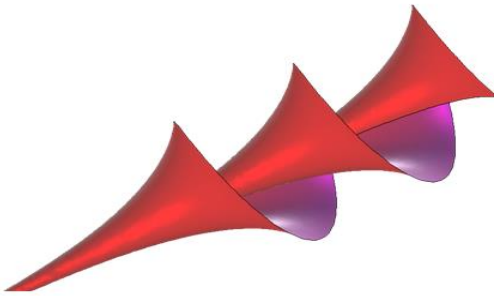

Fig1c Nature inspired Surfaces: Dinis Surface

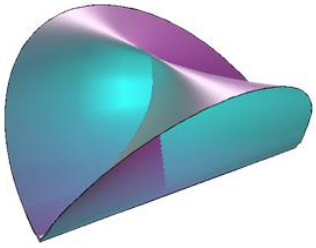

Fig1d Nature inspired Surfaces: Cayley Cubic

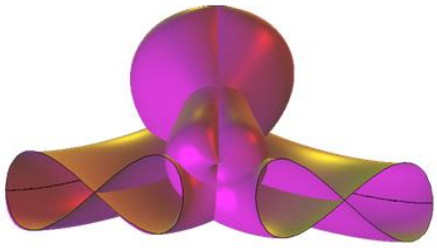

Fig1e Nature inspired Surfaces: Klein Surfaces

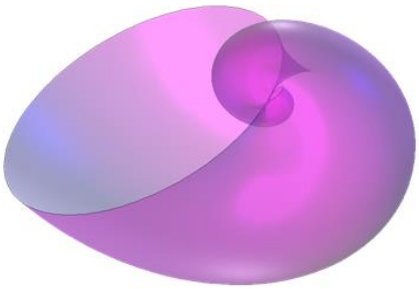

Fig1f Nature inspired Surfaces: Shell surfaces

2.2 Klein Surfaces

Klein surface is a mathematical surface on which the notion of angle between two tangent vectors at a given point and the angle between two intersecting curves on the surface are well defined. The boundary of a compact Klein surface consists of finitely many connected components, each of which is homeomorphic to a circle. These components are called the ovals of Klein surface. Figure 3 shows architectural application derived from Klein surface. The aesthetic design of this model is designed and it's shape is used to produce stiff structures inspired from nature. The generated structures are created controlled by generative algorithms. The given model is an example of mathematical surface derived from Klein surface. This complex model is used to construct nature inspired structure of a stadium.

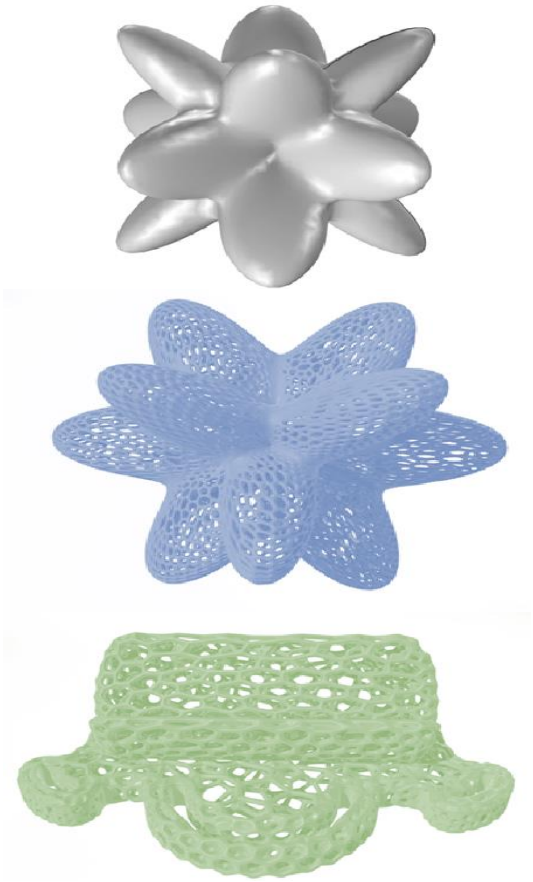

Figure 2. Fresnel Wave surface and Organic Structure

2.3 Gyroid type surfaces

The Gyroid surfaces are developed using parametric surface models with trigonometric equations. A Gyroid surface is an infinitely connected triply periodic minimal surface. Figure 4 shows sample Gyroid surfaces and unit cell of various shapes and surfaces. Gyroid structures have photonic band gaps for novel electromagnetic zero transmission, 100% transmission type applications. The organic patterned structures of Gyroid surface are stiffer and lightweight for cellular solid based materials and structures.

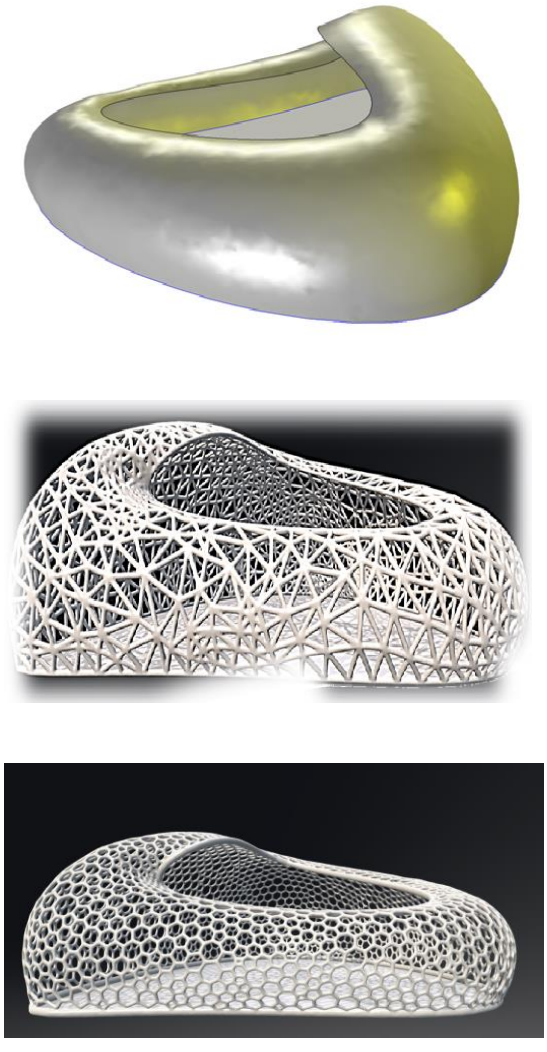

Figure 3. Klein Surfaces inspired Architectural form

3. Nature Inspired Surface to Engineering Structures

Architectural and civil structures, inspired from natural patterns for innovative and functional forms. These innovative forms are engineered by integrating structural triangulation, hexagonal mesh patterns of mathematical surfaces. The mathematical expressions used to construct the shape in Figure 3 is provided below.

$$X=f(u,v)=(3*(1+\sin(v)) + 2*(1-\cos(v)/2)*\cos(u))*\cos(v)$$

$$Y=g(u,v)=(4+2*(1-\cos(v)/2)*\cos(u))*\sin(v)$$

$$Z=h(u,v)=-2*(1-\cos(v)/2) * \sin(u)$$

$$-1<=u<=2,\ 0<=v<=2\pi$$

The generated parametric surface is cut into halves while keeping the desired portion, a filler bottom surface is created to make it stadium alike structure. The aesthetic design of this model is designed and its outer surface is used to produce stiff structures inspired from nature. The generated structures are created and controlled by generative algorithms. Only few of generated structures are mentioned in this paper.

A mesh file was developed to support generative algorithms for creating stiffer, self-supporting and beautiful structural frame. The structural design can later prototyped using 3d printing technologies. These structural triangulation, hexagonal mesh patterns engineered from the aesthetic mathematical surface is an innovative design process which will help architects to design civil structures inspired from nature.

Figure 4 Shows Gyroid inspired engineering Structures. A Gyroid surface is an infinitely connected triply periodic minimal surface discovered in 1970. The Gyroid surface can be trigonometrically formed by the below equation.

$$\sin(x)*\cos(y)+\sin(y)*\cos(z)+\sin(z)*\cos(x)=0$$

Gyroid structures have photonic band gaps that makes them potential photonic crystals. The organic patterned structures are stiffer and lightweight in nature.

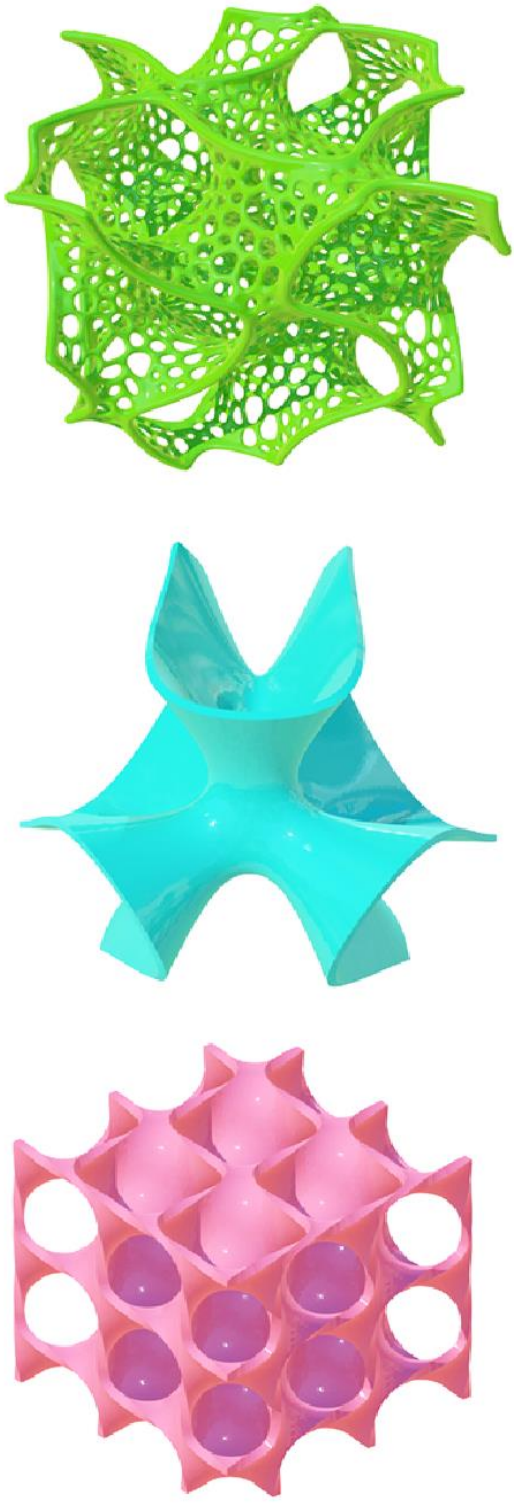

Figure 4. Gyroid type surfaces and Applications

4. Conclusions

The parametric surface feature of COMSOL was leveraged for developing equation based mathematical surfaces into CAD models and innovative 3D printable engineering Structures. The development of Surface model to CAD product and Engineering Structure was detailed. The equation based surfaces, complex but functional 3D printable innovative engineering structures potential was highlighted.

5. References

Type your references here, as needed.

1. Sergey Krivoshapko and V.N. Ivanov, Encyclopedia of Analytical Surfaces, Springer, February 25, 2015.

6. Acknowledgements

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