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O.V.Makukha, senior lecturer
M.O. Makukha, student 101-A
National University
"Yuri Kondratyuk Poltava Polytechnic"

3D THINKING IN MODERN ARCHITECTURE

The past in geometry was dominated by fixed structures, whole numbers end static grids, particularly cubic lattices. The primary 3D space module has been a cuboid - a rectangular box. Moving into the future, we have the technologies and materials to explore 3D space in a whole new way - to investigate the properties of many types of curved and angled surfaces, scale, sequence, proportion, resonance, reflection, absorption, light and sound. Twentieth-century mathematics includes dynamic geometries: I would like to examine some of these, but we also look at new 21st-century geometries that are distinctive in that they are geometries of change. In this, they explore 3D space dynamically and may well be the forerunners of other dynamic geometries that will help us analyze the properties of 3D form from a diverse range of aspects, including physical and psychological, we will explore geometries of mathematical curves, fractals, shape-changers and dynamic spheres.

One way to model or even manufacture radically new architectural forms is to generate them by using equations, and thereby take advantage of today's manufacturing technologies and computer-aided design systems (CAD). To create the equations we need to render the forms in three-dimensional space using mathematical means to identify every surface and position of the form. One of the ways to do this is to adopt a way of thinking formalized by the 17th-century French philosopher and mathematician René Descartes, who provided us with a powerful way of positioning points, shapes and objects in three-dimensional (Euclidian) space, using what we might call x, y, z rectangular thinking.

Thinking in grids. Thinking within three-dimensional rectangular (x, y, z) grids is not new, and has its origins in ancient Egypt, where statues and architectural spaces were proportioned within cubic lattices. In Renaissance Europe scientists and artists resurrected the ancient Greek study of optics and formalized the logic of perspective, which organizes 2D space with a 3D modelling system of grids aligned with vanishing points, with the grid used to proportion 2D images in such a way that they have the appearance of 3D objects. The Cartesian coordinate system, as developed by Descartes in 1637, continued the logic of dividing space into 2D and 3D grids. It corresponds with the Egyptian cubic grid system but is much more versatile and provides us with a means to organize space in three directions, called the three axes, each at right angles to the other: x, y and z. Two- and three- dimensional forms can be plotted in Cartesian space using (x, y, z) values generated from a logical sequence, or set of operations, called mathematical equations or algorithms.(Pic. 1).

Modelling forms. Natural forms that appear to follow some sort of sequential or symmetrical logic can often be approximated with equations and can, as algorithmic steps, be inserted into software or strings of code to generate

2D and 3D images or 3D physical objects. A 2D or 3D equation is a means to concisely communicate a set of instructions that will generate plots in 2D or 3D space using a step-by-step logic. The logic can also be written out as a step-by-step set of operations, known as an algorithm. A computer program follows the same step-by-step logical process used to create an equation.

Creating an equation to generate a natural-looking form necessitates a level of simplification.

The type of spiral, where the distance from the center increases exponentially from a center point in terms of its angle of rotation, is called a logarithmic spiral. The same equation with different values of “a” and “b” can be used to plot, for example, the curve of a nautilus shell or Romanesco broccoli. In an Archimedean spiral (pic. 2) the distance between the arms does not exponentially increase with distance from the center (the distance stays the same).

Many types of mathematical equation are used to generate forms in two- and three-dimensional space.

As our two - and three-dimensional models become more complex, equations written in the parametric form become more concise to use than rectangular equations (pic. 3).

Hyperboloids. A hyperboloid (pic. 4) is a doubly ruled surface that can be built with straight steel beams, producing a strong structure at low cost. Examples include the cooling towers of power stations, the James S. McDannell Planetarium building at the St Louis Science Center, and the Kobe Port Tower in Japan (pic. 9).

Toroids and Klein bottles. An example of distorting a plane to create a 3D form can be seen in the forms of toroids, and similarities can be seen between the parametric equations for the toroid (pic. 4) and the sphere. The difference between the torus and the twisted immersion Klein bottle (pic. 5) is really just that of the surface: the surface twists on the latter, so the inside surface becomes the outer. Famous toroids in architecture include the Joint European Torus in Oxfordshire, England, which is the world's largest plasma physics experiment, and the Stanford University, California, torus designed as a possible space habitat, A Klein bottle house with flat surfaces rather than curves has been built in Melbourne, Australia, by architects McBride Charles Ryan. Boy's surface The Boy's surface (pic. 6) has a three-fold symmetry and can be cut into three equal pieces

Hyperbolic paraboloids. The Cartesian equation of the hyperbolic paraboloid (pic. 6) is similar to that of the elliptic paraboloid (pic. 3), but the x value is negative and thereby creates an opposing curvature to the y value. The saddle - like form is the result of the opposing curvatures. The second hyperbolic paraboloid in pic. 6 is known as the 'monkey saddle' because the saddle form has a third depression that could supposedly accommodate a monkey's tail.

Conchoid and Kuen's surface. As equations get more complex so too can the forms that they generate. The parametric equation generates a seashell-like conchoid. The forms that equations can generate are probably infinite. The Kuen's surface has a constant negative curvature and is a special case of a whole family of three-dimensional surfaces known as Enneper's negative curvature surfaces. The surface has the same Gaussian curvature as a sphere and pseudosphere. Equations of 3D forms can easily be modified to change the curvatures and the number of saddles and arches. Once generated, the forms can be interconnected in a modular fashion, or stacked on top of themselves. Pic.7 shows a possible combination of an equation-generated toroid.

New methods and materials. We are entering a new era of structural design made possible by adding Internal cellular structures to materials, where we can use mathematical equations to generate cellular structures that maintain or increase the internal structural integrity of materials while reducing the overall weight of the material and therefore reducing the need for external structural support such as triangulated frameworks, cantilevered frameworks or suspension cables.

3D-printed assemblies of cellular-structured materials can create formed material structures that can be fixed and/or flexible - so that, for example, parts of a structure can freely bend or otherwise change shape, vibrate or resonate - or be fixed and inflexible. The possibilities seem endless: architectural structures with capacitance circuits, heat-generating circuits, structures that change shape and position, transparent and opaque structures, fluid-carrying structures, and so on.

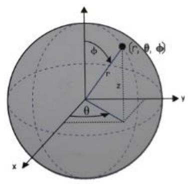
The use of new-generation 3D printers, combined with cellular materials and new-technology coatings, creates the opportunity to design radically different architectural forms. The external structural architecture can be of many types, such as fixed polyhedral forms, shape-changing polyhedral forms, spherical forms or clusters, bubble structures, and forms that follow mathematical or natural 3D cursive forms. This would fundamentally change the nature of the 3D structures that we might see in cities, in the air, on the roads, under the sea and outside the Earth's atmosphere.

Generating 3D forms without equations. As technology develops, the need to render the mathematical equations of 3D forms in a programming language will probably disappear as even higher- level languages and computer interfaces evolve. 3D modelling software has been available for many years and an almost infinite number of forms can be generated without using equations of any sort.

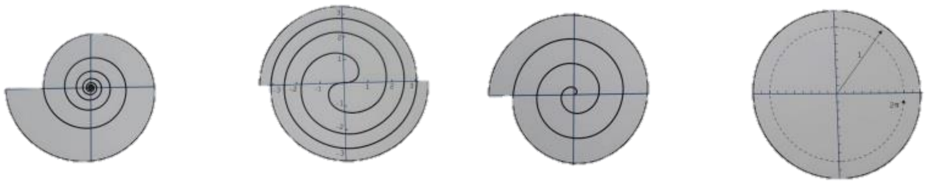
There are many types of 3D software available. The Guggenheim Museum in Bilbao, Spain (pic. 8), designed by Frank Gehry, features complex, apparently random curves generated using the CATIA (computer-aided three-dimensional Interactive application) software. The software was used to digitize points on the edges, surfaces and intersections of Gehry's hand-but models to construct on-screen models that could then be manipulated from different perspectives.

We have also seen the use of 3D scanners that can render an existing 3D form digitally such that the digital form can be used to replicate a given object, or create any sort of variation, or combination, of an existing 3D form.

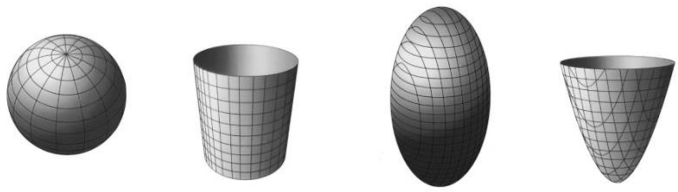
Almost any shape should be 3D printable whether it is printed as component parts or in one piece.



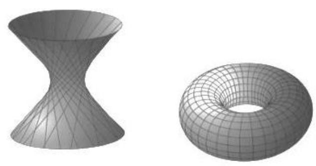
Pic. 1. Polar coordinates



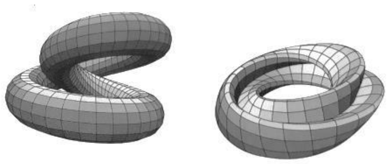
Pic. 2. Logarithmic, Archimedean spiral, fermat spiral and circle.



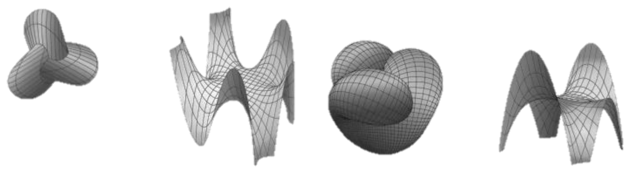
Pic. 3. Sphere, cylinder, ellipsoid, elliptic paraboloid.



Pic. 4. Hyperboloid and torus.



Pic. 5. Toroid and immersion of a Klein bottle



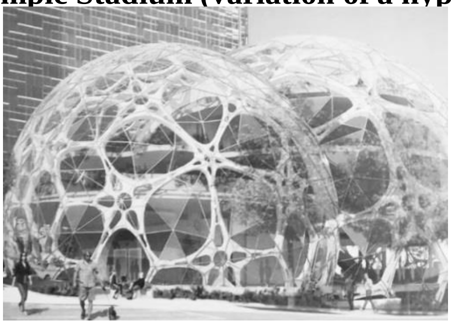
Pic. 6 Two variations of a Boy’s surface and hyperbolic paraboloids.

Pic. 7. Toroid assembly


Pic. 8. The Guggenheim Museum in Bilbao, Spain (pic. 8), designed by Frank Gehry


Pic. 9.Kobe Port Tower, Japan (hyperboloid).


Pic. 10. Munich Olympic Stadium (variation of a hyperbolic paraboloid).


Pic. 11. Amazon biodomes.

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