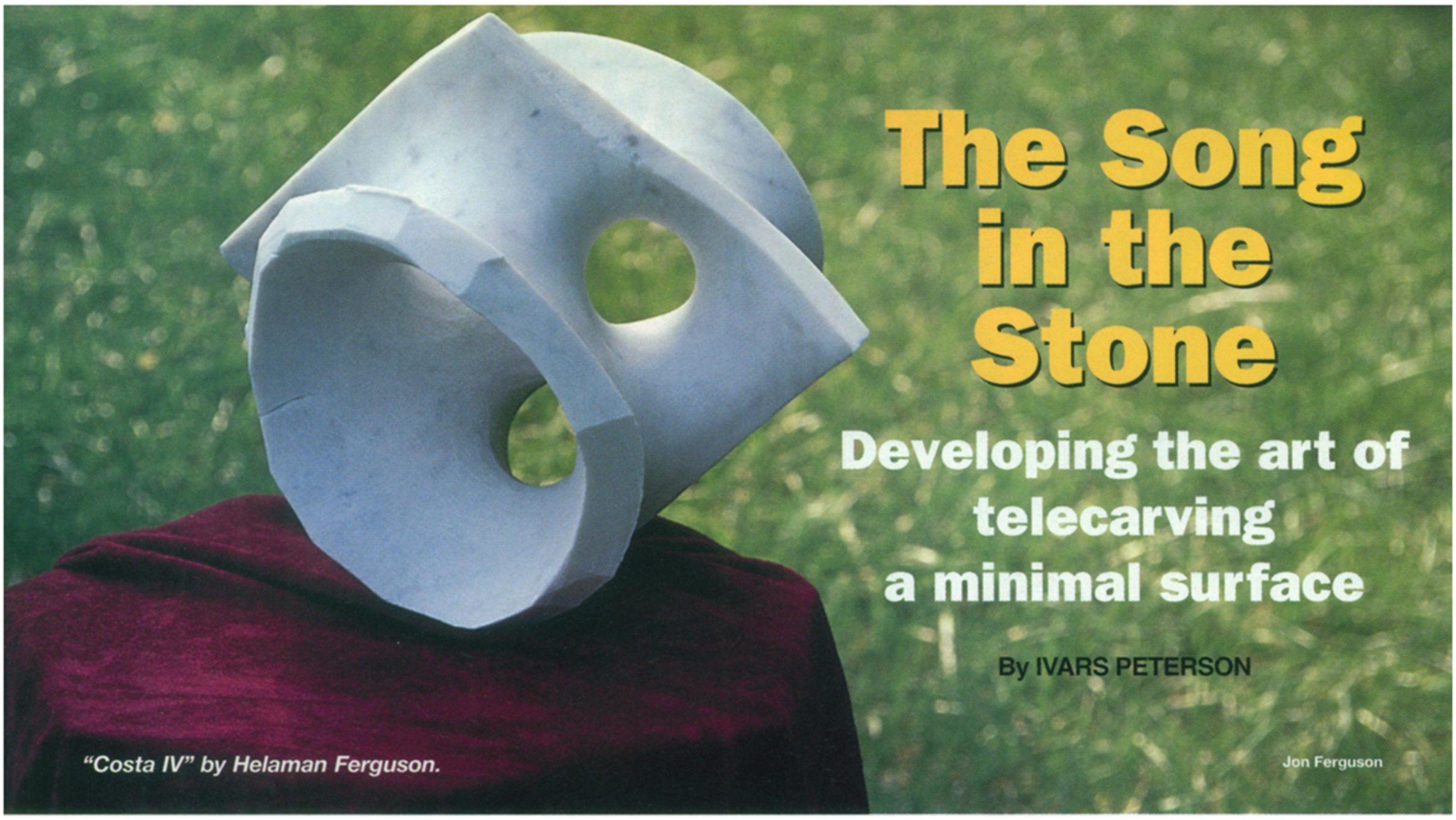


The Song in the Stone

Developing the art of telecarving a minimal surface

By IVARS PETERSON

"Costa IV" by Helaman Ferguson.

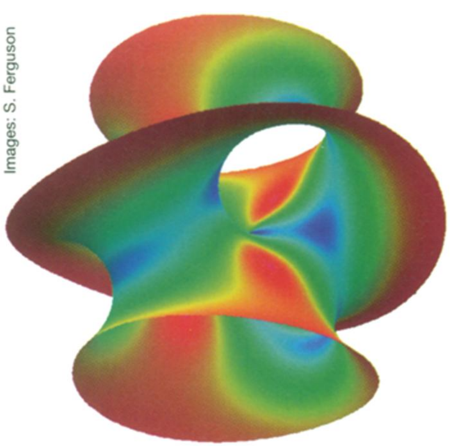
Jon Ferguson

The Song

From the outside, Helaman Ferguson's modest, two-car garage resembles just about any other garage in his suburban neighborhood near Laurel, Md. Inside, it has the look of an industrial site.

Ropes, cables, pipes, and hoses twist through the cluttered space. A steel framework juts down from the ceiling. A hefty drilling machine hangs nearby, next to a huge, industrial-strength vacuum cleaner. An ancient Macintosh-II computer sits in its dust-proof case atop a high shelf. Blocks of stone occupy odd corners. Heavy padding covers the walls to muffle the drill's screech and the dust catcher's rumble.

Images: S. Ferguson



Four views of the Costa minimal surface as rendered on a computer screen. The colors represent the amount of curvature, ranging from nearly flat (red) to highly curved (purple).

This is Ferguson's studio. Here, he carves stone and other materials to fashion works of art rooted in mathematical ideas (SN: 9/8/90, p. 152).

Shaping stone is a gritty, noisy, even violent process. Yet amid the roar and dust, a sculptor can hear the song of the stone.

"When you carve stone, it sings back to you," Ferguson muses. With every stroke, the stone vibrates and rings, and when everything is going well, its tones are pure and sweet to the hand and ear.

"When it quits singing, you know you're in trouble," he remarks. The carving may have uncovered fractures; the stone may have lost its strength and integrity. The sculpture may be flawed.

Lately, Ferguson has been hearing a particularly harmonious melody as a graceful, 3-foot-tall figure gradually emerges from a gleaming chunk of white Carrara marble. This sculpture is one of a series based on a type of mathematical form called a minimal surface. It's related to the shape of a soap film stretched across a bent ring.

"I expect this piece to be quite bell-like, quite musical in many ways," Ferguson says.

"As I carve it, I can listen to its ringing," he affirms. "And its curvature seems to make it strong."

This sculpture represents the latest turn in an exploration that started more than two centuries ago with observations of soap films in nature. In the years that followed, mathematicians developed equations to describe such surfaces.

A decade ago, researchers probing these generic equations uncovered a novel minimal surface that no one had seen before (SN: 3/16/85, p. 168). Inspired by this new surface, Ferguson's sculptures complete the cycle back to a physical form, making concrete what was initially just equation and computer-generated picture.

The Projector

Sculptors often make a small model, or maquette, of what they want to carve. Traditionally, they have used a contraption called a pointing machine to transfer measurements from the maquette to a block of stone to make an enlarged reproduction. Though effective, the process is cumbersome and time-consuming, and it's useless without a solid model to copy.

Ferguson has pioneered an alternative approach. Using equipment developed by James Albus and his coworkers at the Robot Systems Group at the National

Institute of Standards and Technology (NIST) in Gaithersburg, Md., he can translate geometric forms drawn on the computer screen directly into instructions on how much material the artist should remove at any point from an uncarved stone's surface to reveal the object.

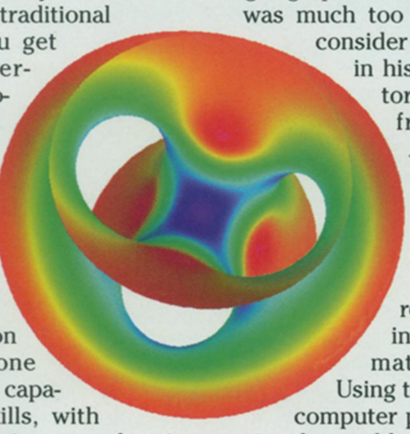
"It's like when you were a little kid and had something buried somewhere," Ferguson says. "You knew this thing was there, but you didn't know quite where it was until you started digging it out."

With the NIST apparatus, the sculptor's task becomes that of chipping away the excess material to reveal a figure that already exists in the stone.

The NIST virtual image projector consists of two rigid, equilateral triangles: a large one fixed to the ceiling of Ferguson's garage and a smaller one suspended from the first by six cables. Attaching a high-speed water jet, air drill, or other cutting tool to the lower triangle, the sculptor can move this triangle around to direct the carving process.

Sensors register the varying lengths of the six cables as the lower triangle moves about, and a computer program works out the tool's position and orientation at any given moment. When the tip of the tool touches the stone, the computer also calculates the distance from that spot to the nearest point on the virtual image of the surface yet to be unearthed. That tells the sculptor how much he can cut away safely.

"Compared with the traditional pointing machine, you get a lot more flexibility," Ferguson says. "The process can also be more quantitative, down to a precision of a millimeter or so."



For NIST, this project represents new technology—a new machining process. The virtual image projection system combines in one package both high-tech capabilities and human skills, with each component focusing on what it does best.

People, for example, are very good at plotting trajectories, circumventing obstacles, and getting from one place to another efficiently. Machines provide the additional precision and power needed.

This combination of human and machine capabilities makes Ferguson's system, whose action the operator guides, much less expensive than industrial, computer-controlled milling machines, which follow step-by-step instructions to cut and grind metal and other materials into machine parts.

"In my studio, I'm testing this kind of equipment under really hazardous conditions, testing it to do things more complicated than machine parts," Ferguson says.

The Equations

Ferguson is fascinated by surfaces, and his training as a mathematician allows him to work with equations describing an infinite array of these geometric forms. "I can start with equations and create things that no one has ever touched before," Ferguson says. "That's what excites me artistically."

But getting the right equations to use with his virtual image projector isn't always a simple matter. His efforts to sculpt a new type of minimal surface—discovered about a decade ago by Brazilian mathematician Celso J. Costa—illustrate the difficulties.

The Costa surface is an example of a "complete embedded minimal surface of finite topology." Roughly speaking, this means that the surface has no boundary and doesn't fold back to intersect itself (see illustrations). It also has the characteristic curvature of a minimal surface (SN: 10/24/92, p. 276).

Such a curvature resembles that of a potato chip, which typically starts out as a flat, thin slice of moist potato. As it dries out during frying, the chip shrinks. Minimizing its area, it curls into a saddle, or hyperboloid, shape. Every little section of the Costa surface has this saddle configuration.

Initially, using Costa's equations for the surface, mathematicians needed hours of computer time to create even a single graphic image of the form. This was much too long for Ferguson to consider using these equations in his virtual image projector. But he got some help from mathematician Alfred Gray, an expert on differential geometry at the University of Maryland in College Park.

Gray found a way of rewriting the equations in terms of a different mathematical function. Using this new formula and a computer program called Mathematica, he could produce images of the Costa surface from just a few lines of instructions in a matter of minutes.

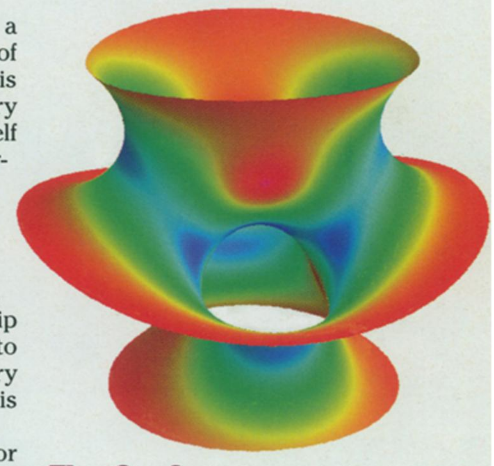
"The equations for Costa's surface are really complicated," Gray says. "I fooled around with identities and elliptic functions until I finally understood what was going on."

Ferguson then adapted Gray's formula for use with the relatively modest computer operating his virtual image projector. Working with his son Samuel, a graduate student in mathematics at the University of Michigan in Ann Arbor, Ferguson refined the computer recipes, or algorithms, and wrote a program for speedily computing the required parameters.

"We made it really fast," says Ferguson, who also works at the Supercomputing Research Center in Bowie, Md. "Now we can bring up a picture in a few seconds."

This meant that he could carve the Costa surface without waiting interminable intervals for his virtual image projector to calculate the necessary distances. Ironically, Ferguson's desire to do this particular sculpture also resulted in the development of new mathematics.

He described these mathematical underpinnings and displayed some of the resulting sculptures at a meeting of the International Society for the Interdisciplinary Study of Symmetry, held last August in Alexandria, Va.



The Surface

Ferguson has so far produced a number of Costa surfaces, including a 16-inch version made of textured bronze and aluminum, a 10-inch marble structure (see cover), and the molds for a 3-foot sculpture.

He delights in the novel perspective these forms bring to mathematics. "You get to feel a minimal surface that doesn't go pop when you touch it," he notes.

Ferguson now wants to do a 10-foot version of the Costa surface—one large enough for kids to slide through. "Wouldn't you like a seat-of-the-pants understanding of minimal surfaces?" he asks.

Though inspired by mathematics, these sculptures are not precise mathematical models. A mathematical surface has no thickness, but the sculpture must support itself and stand up on its own. And whereas the Costa equations specify forms of infinite extent, the artist must decide where to truncate the structure to create a visually appealing form.

By fashioning mathematically based shapes, Ferguson adds to his sculptural palette. "One place I get new surfaces is from equations, and we have an inexhaustible supply of them—things that we have never experienced before," he says. "As I do one of my quantitative carvings, I learn the surface. Then I can use it in other places."

Ferguson's sculptures convey not only the visual beauty, harmony, and symmetry but also the sound and feel of mathematics. These are edifying experiences for artist, mathematician, and onlooker. □