Realization of Two New Large-Scale Sculptures

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Abstract

Two new sculptures, conceived and designed by Brent Collins and Carlo Séquin, are currently in their final phase of fabrication and are scheduled to be installed in May or June of 2012 in a Science Building at Missouri Western State University. Here we report on the geometrical design of these two sculptures and on the technical challenges encountered in fabricating them at the 6-foot scale.

1. Introduction

In 2010, Brent Collins obtained a commission for two geometrical sculptures for a science building in Missouri Western State University (MWSU). He contacted Carlo Séquin and enlisted his help to carry out the detailed geometrical designs using the computer tools that had been created at U.C.Berkeley over the last decade to capture and enhance the shapes of some of Collins' abstract sculptures. The two sculptures are "*Music of the Spheres*," a curved bronze ribbon winding around 6-foot diameter virtual sphere, and "*Evolving Trefoil*," an intricately structured "cord" composed of 24 saddle/tunnel segments of translucent epoxy wrapped into a symmetrical clover-leaf knot.

Ideally such abstract geometric sculptures first capture a spectator's attention just through their engaging form, which may contain a judicious balance between symmetry and irregularity to enhance dynamic tension. As the viewer engages more closely with such a sculpture, additional details and more subtle geometrical relationships may become apparent. Finally, as the visitor studies up on the background information and learns about some of the underlying mathematical principles displayed in a particular sculpture, an even deeper level of appreciation and enjoyment may result.

Conceiving of such sculptures at the geometry level is only the first phase in a rather lengthy process, which culminates with the installation of a sculpture at its final destination. Many problems have to be solved along the way to enable a reasonably cost-effective translation from a computer file to the geometry master required for fabrication, and the efficient replication and assembly of the various sections into a robust and stable sculpture that can withstand the hardships of transportation, installation, and the long-term influences of the environment at their final destination.

2. Collaboration

The collaboration between Prof. Séquin and wood sculptor Brent Collins, living in Gower, MO, started in 1994. It was prompted by a picture of a small wood sculpture called *Hyperbolic Hexagon*. This toroidal chain of six holes and saddles is reminiscent of the central portion of Scherk's *2nd Minimal Surface*. Séquin wrote a computer program, called *Sculpture Generator I* [5], to capture this basic paradigm, He generalized it to include higher-order, twisted saddles and introduced controls to adjust the number of hole-saddle units and to fine-tune the thickness and extension of the flanges. This program was used in 1996 to design the wood master for *Hyperbolic Hexagon II*, the first large-scale collaborative piece (Fig.1). The fine-tuned design, agreed upon by Collins and Séquin, was captured in a set of twelve full-size blueprints, representing cuts 7/8 inch apart through the whole form. Collins cut these patterns from wood boards of corresponding thickness. After stacking and gluing them in the proper order, he then brought out the fine geometric details of the hyperbolic surfaces using his skills as a wood sculptor, honing the overall shape to perfection (Fig.1a). This original stood for several years in the Mathematics Lounge of Wesleyan College. There it was discovered by the film makers of "Watchmen" and borrowed for an appearance in Dr. Manhattan's studio. In 2008 a mold was formed from this wood master, and Steve Reinmuth's Bronze Studio in Eugene, OR, [3] then reproduced the shape in bronze by investment casting. Steve Reinmuth also applied the special patina that turns a "geometric model" into a piece of art. Thus the bronze version of *Hyperbolic Hexagon II* (Fig.1b) is the result of a truly collaborative effort by Brent Collins, Steve Reinmuth, and Carlo Séquin.

Figure 1: *"Hyperbolic Hexagon II": (a) 1997 wood master carved by Brent Collins; (b) 2009 bronze sculpture cast by Steve Reinmuth, installed in Sutardja Dai Hall at U.C. Berkeley.*

That same team is again responsible for the creation of *Music of the Spheres*. This time Steve Reinmuth faced a particular challenge to realize this airy form with its long delicate ribbon, sweeping through space for many feet without any intermediate support. The lower segments of the ribbon are cast solid to provide maximum strength and stability; the upper branches are cast as hollow tubes to provide reasonable strength, coupled with minimal weight.

For *Evolving Trefoil* the team relies on the experience and expertise of David Lynn of Nova Blue Studio Arts in Seymour, MO, [2] to faithfully replicate the computer-generated geometry true to form and with attention to a pleasing surface finish. The intricate higher-genus geometry provides significant challenges in this final finishing phase.

3. Design of "*Music of the Spheres*"

A warped ribbon closing back onto itself is a symbol of infinity. The ribbon in *Music of the Spheres* conceptually loops around a large invisible sphere and partly around three smaller spheres that touch the large sphere tangentially on the inside (Fig.2b). This system of nested spheres evoked the association with an early Greek view of our solar system and inspired the name for this sculpture, referring to Kepler's mystical view of the planetary orbits. The geometry follows an original wood model crafted by Brent Collins in the mid 1990s (Fig.2a). The ribbon forms a 3-fold symmetrical trefoil knot, which, however, offers somewhat different views from the "front" and from the "back." This enhances the visual interest as the viewer walks around this sculpture. The ribbon itself has a narrow, crescent-shaped cross-section. The concave part of this profile always points outwards in any bend made by the ribbon. This forms a narrow, elongated saddle surface that yields mechanical strength as well as intriguing visual effects: The points where the ribbon seems to flip over appear to change their positions depending on the observer's viewing direction. The structure has an obvious 3-fold rotational symmetry, and this is exploited in order to minimize the number of geometrical master modules that need to be defined and fabricated. However, one third of the whole ribbon is far too big to be cast as a single piece. The geometry is therefore partitioned into 18 segments requiring six unique molds to be made (Fig.2c).

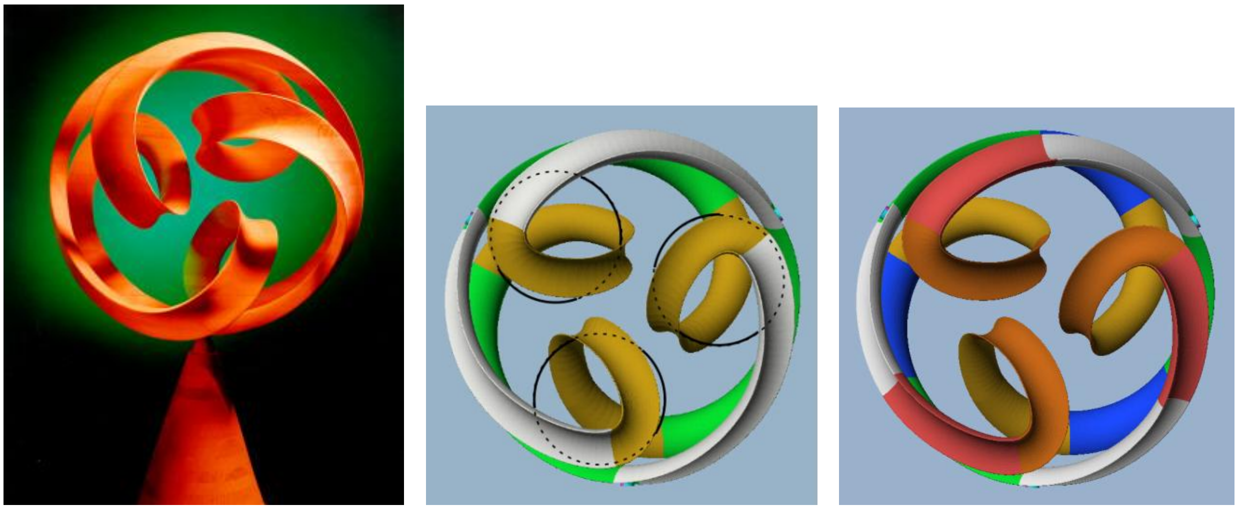

Figure 2: *(a) Collins original "Music of the Spheres" photographed by Phillip Geller; (b) analysis and modular redesign for a scaled-up bronze sculpture; (c) decomposition into 18 segments.*

For aesthetic reasons, the cross section of the ribbon is not kept constant. As it approaches the center of the sphere it is slightly reduced in scale. This is easy to achieve, as the generating program used by Séquin can smoothly vary the cross section of a sweep along an arbitrary space curve. The resulting final design can be seen in Figure 3 from three different viewing directions.

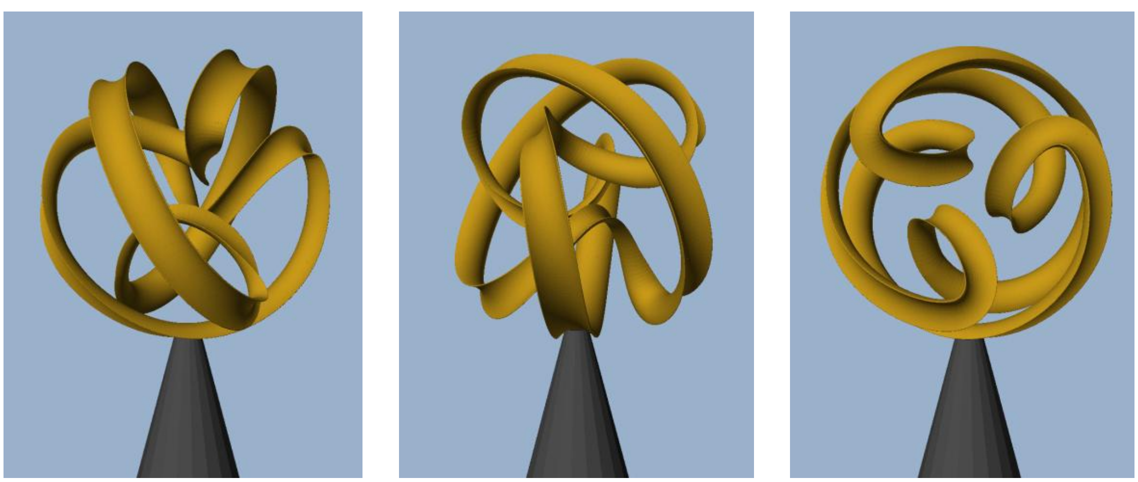

Figure 3*: The final design of "Music of the Spheres" seen from different directions.*

4. Construction of "*Music of the Spheres*"

The master geometry of this sculpture, which is captured by one third of the segments shown in Figure 2c, is carved from high-density foam material on a numerically controlled milling machine. Each segment measures between 2 and 3 feet in length. These machined pieces are then covered in wax so that their surfaces can be smoothed enough to yield good negative molds of the various segments. Three separate wax copies are then drawn from each mold and are individually subjected to a traditional investment casting process. Once the cast bronze has cooled down, and the ceramic shell has been removed, the really artistic phase of fabricating a large bronze sculpture begins. Each piece has to be cleaned and freed of its runners and vents. The individual pieces have to be assembled in perfect alignment, and the bronze welds have to be smoothed out so that no visible trace in the surface reveals the fact that this sculpture has been assembled from multiple pieces. Finally the whole surface has to be polished and provided with some distinct patina, and optionally with some protective coating – a thin layer of wax or epoxy.

A previous ribbon sculpture, *Pax Mundi*, cast in 2007 [1] gave us an unpleasant surprise as it sagged under its own weight by about 15%, thus outlining an overall shape noticeably different from the desired spherical form. Steve Reinmuth [3] was able to correct this flaw by hanging the sculpture from the highest point of the ribbon and cutting halfway through the major bends of the ribbon (Fig.4a), thereby letting the structure stretch by an additional 15%. In this elongated state he then filled the cuts made into the ribbon with bronze weld, locking in this stretched shape. Subsequently, as the ribbon was mounted again from its lowest point supported by a conical pedestal, it sagged under its own weight into an almost perfect spherical shape.

Figure 4: *(a) Adjusting the overall shape of "Pax Mundi" by opening up some of the hairpin turns. Calculating gravitational deformation: (b) for "Pax Mundi" (c) and for "Music of the Spheres."*

With *Music of the Spheres* we were keen to avoid this "detour" in the fabrication process. First, we designed a somewhat thicker and stiffer ribbon. We also subjected the final design to a structural analysis program that shows in color-coded form how much each part of the geometry moves away from its designed position under the influence of gravity (Fig. 4b and 4c): Blue means no movement; red indicates a displacement of about 15% of the overall bounding box around the sculpture. Even though the simulation results for *Music of the Spheres* were quite encouraging (Fig.4c), Steve Reinmuth decided to reduce the chance of sagging even more. He proceeded to cast as hollow tubes the upper ribbon segments that act primarily as "ballast" rather than as supporting structure. Only the main segments emerging from the supporting pedestal will be cast solid to yield maximal strength. Figuring out how to cast these segments as hollow tubes was quite a challenge and it delayed the completion of the sculpture by several months. It was difficult to find the right kind of material to form the needed core in each tubular segment; it was difficult to hold that core in place nicely centered within the ribbon profile; and the drying out of the plaster shell parts in the core was taking several days.

Figure 5 gives a few glimpses of the fabrication process. Figure 5a shows three of the molds used for this sculpture, and Figure 5b shows one of the wax parts cast in one of those molds. These wax parts are then sprayed with plaster slurry (Fig.5c), which when dried out (Fig.5d, 5f) and heated in the kiln will form the ceramic shell for the investment casting process. Figure 5e shows and end-on view of one of the molds for a hollow tube segment; it is evident that the inner geometry is quite tight!

Figure 5: *Fabrication of "Music of the Spheres": (a) A primary mold for casting wax replicas of a particular segment; (b) wax replica cast in such a mold; (c) spraying the wax part with plaster slurry; (d) wax part covered with ceramic shell; (e) mold for casting a hollow part; (f) more shells waiting for investment casting.*

5. Design of "*Evolving Trefoil*"

The overall shape of the second sculpture maintains the structure of a symmetrical trefoil knot (Fig.6c). But here the knotted cord is not just a simple ribbon, but a structure that is derived from a geometrical form discovered in 1834, known as Scherk's 2nd minimal surface [4]. The core of this infinitely large minimal surface forms a chain of alternating saddles and tunnels (Fig.6a), and all portions of this geometry are in the shape of a soap film suspended between wires corresponding to some lines on this surface. We have extracted this interesting central portion to form the "cord" of our knotted sculpture. Actually we use third-order saddles (also known as monkey-saddles) with three ridges bounded by six edges emerging from either side of the saddle surface. The whole cord contains 24 such third-order saddles and it is given an additional longitudinal twist of 360° degrees to evoke the association with a spiraling DNA chain and to add visual interest to this sculpture.

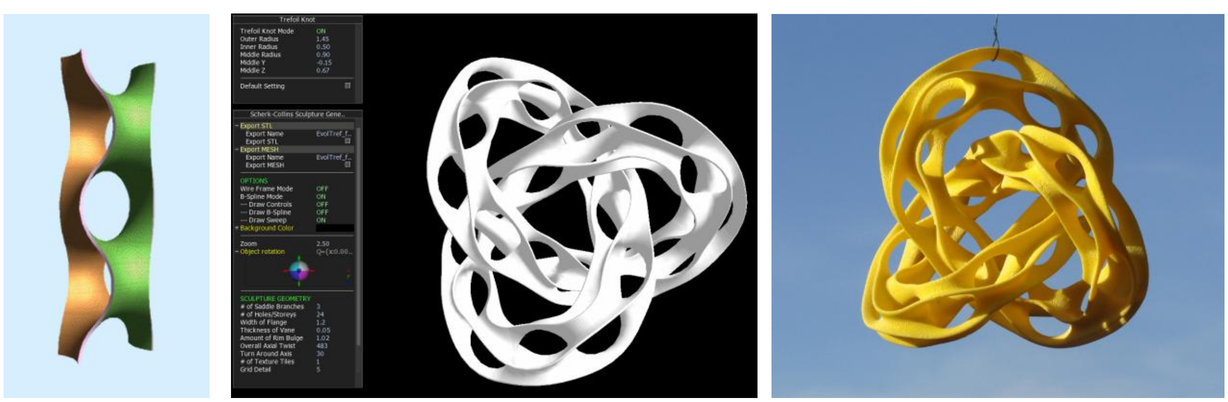

Figure 6: *(a) The core of Scherk's 2nd minimal surface. (b) 24 3rd order Scherk stories forming a trefoil knot. c) Maquette of "Evolving Trefoil" made on a fused-deposition modeling (FDM) machine.*

The geometry of this sculpture was generated in a special-purpose program developed over many years by Carlo Séquin and several of his students. The program explicitly describes the geometry of one of the minimal saddle geometries and then strings together multiple copies along an arbitrary space curve, with fine control over any twisting and/or scaling of the radial dimension of the cord (Fig.6b). All parameters have been carefully adjusted to maintain a full 6-fold symmetry of type D_3, so that the overall sculpture is completely defined by just 1/6 of its geometry (Fig.8a).

Overall this sculpture is a trefoil knot, and thus reflects geometry and mathematics. Its realization as an optimized cubic spline, with a Scherk-Collins saddle/hole chain slung along that spline, represents the fields of engineering and of computer-aided design. Finally, its substructure is vaguely reminiscent of the skeletal structure of a cholla cactus or of the twisted chains in our genes, and thereby also celebrates the bio-sciences, life, and its evolution.

6. Fabrication of "*Evolving Trefoil*"

In 2007 David Lynn and Nova Blue Studio Arts, L.L.C., in Seymour, MO, [2] helped us realize *Millenium Arch* (Fig.7) hanging in a community center in City of Overland Park, Kansas. They helped with the creation of the master geometry (Fig.7a) and did the molding (Fig.7b), casting, and installation (Fig.7c) of this 10-foot sculpture. So this was the clear choice for us to fabricate *Evolving Trefoil*.

Figure 7: *Realization of "Millenium Arch": (a) NC-machined master geometry module; (b) mold made from master module; (c) installing the completed sculpture.[Images by David Lynn, Nova Blue Studio Arts, L.L.C.]*

However, *Evolving Trefoil* has more than twice the bulk of *Millenium Arch* and it will be placed in a less protected environment. Thus David Lynn modified the fabrication procedure quite a bit to create a sculpture that can withstand the weather, weight, and complexity. The data defining the master geometry, comprising 1/6 of the whole sculpture (Fig.8a), was transmitted to an NC milling machine, where a full-size master was cut out of foam core. This template was then coated with clay (Fig.8c) to provide a smooth surface for mold making; it weighs about 40 pounds. Figure 8b indicates how several copies of this module will eventually be fit together end-to-end.

Figure 8: *The geometry of "Evolving Trefoil": (a) the unique geometry module; (b) three maquettes of this module joined to form half the trefoil; (c) full-size geometry module coated with clay [Image by David Lynn].*

This coated NC master was used to form the mold for one such section. Such a mold consists of 20 parts that are bolted together with more than 100 bolts (Fig.9a). The rainbow coloring indicates where each part belongs in this assembly. Each part itself has two essential components (Fig.9b): the pink silicone rubber mold that defines the smooth surface and all the fine details of the geometry, and the blue fiberglass shell that holds the silicone layer rigidly in place and gives the assembled mold some stability (Fig.9c).

Figure 9: *Main mold for "Evolving Trefoil": (a) assembled mold for the master module; (b) the two parts of a mold segment; (c) silicone mold fitted onto fiberglass shell. [Images by David Lynn]*

To create the main mold, the somewhat fragile master module was suspended in two specially designed end-cap molds that hold the three delicate prongs at each end firmly in place (Fig.10a), and which will also provides each cast segment with male/female slide-together adapters at each prong. A silicone rubber layer is first applied to the surface of the template to yield a mold with a smooth surface that can also replicate any fine geometric details where needed. On top of that, several layers of FRP (fiber reinforced plastic) meshing bonded with Epoxy form the fiberglass shell (Fig.10b).

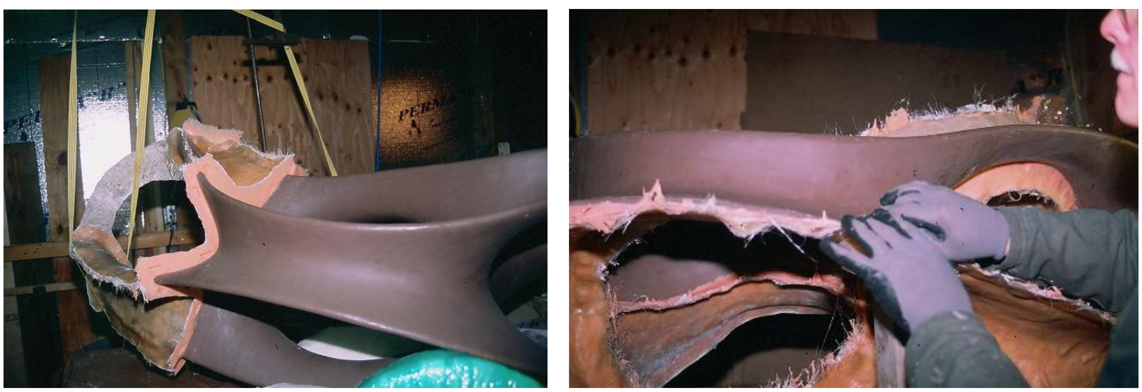

Figure 10: *(a) One of the end-caps holding the template in place for mold making; (b) forming the fiberglass shell of the mold. [Images by David Lynn]*

A framework of steel rebar is holding each mold part in place (Fig.11a) during the lay-up process, so that the pieces can be bolted together with the exact desired geometry (Fig.11b). The hollow form built in this way is filled compactly, section by section, with many layers of fiberglass. When all the sections have been laid up, the *catalyzed matrix* is added. This is a mixture of epoxy resins and crushed minerals blended together with a catalyst; it exhibits the viscosity of cool syrup. Then the mold is quickly sealed up, because the catalyzed matrix remains fluid for a limited time only. The assembled mold with the matrix inside will weigh over 300 lbs (Fig.11c). It is slowly rolled around its long axis and tilted back and forth during the curing/hardening process to avoid uneven matrix distribution and the formation of undesirable hot spots of higher density. The catalyzed matrix joins the seams and fills the gaps. Since one cannot look inside the mold to see how fast the matrix runs, this phase of the process relies a lot on past experience.

When the casting is removed from the mold (Fig.12) it will continue to cure at room temperature for up to 30 days before it reaches full strength. However, it can be worked on within a couple of days. This involves a lot of sanding and grinding to remove the mold releases and the epoxy blush (the latter is part of what epoxy leaves behind when its inhibitors change).

Figure 11*: Molds for "Evolving Trefoil": (a) One mold section on the lay-up dolly; (b) several sections held in place by a framework of steel bars; (c) completely assembled mold. [Images by David Lynn]*

Figure 12*: (a) One of the end-cap molds; (b) part of the end-cap mold and a cast section just out of the mold, waiting to be cleaned up. [Images by David Lynn]*

Conclusions

Few people seem to be fully aware how much work is involved in fabricating and installing a large-scale sculpture. It is not too difficult to design a sophisticate shape on a computer. It is much harder to then realize that shape out of tangible materials that can withstand the stresses imposed by the physical world at the location of their installation – which definitely include gravity, but may also comprise wind and weather, as well as people touching it or even climbing on it. Furthermore it should be pointed out more often that, while the overall geometry of a sculpture is important, the quality of the craftsmanship used in finishing a piece is equally important for the final aesthetic appeal of the completed sculpture. Thus it is only through a combination of dreamers and designers, like Collins and Séquin, with dedicated craftsmen, like Reinmuth and Lynn, that a true piece of art can be completed.

References

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